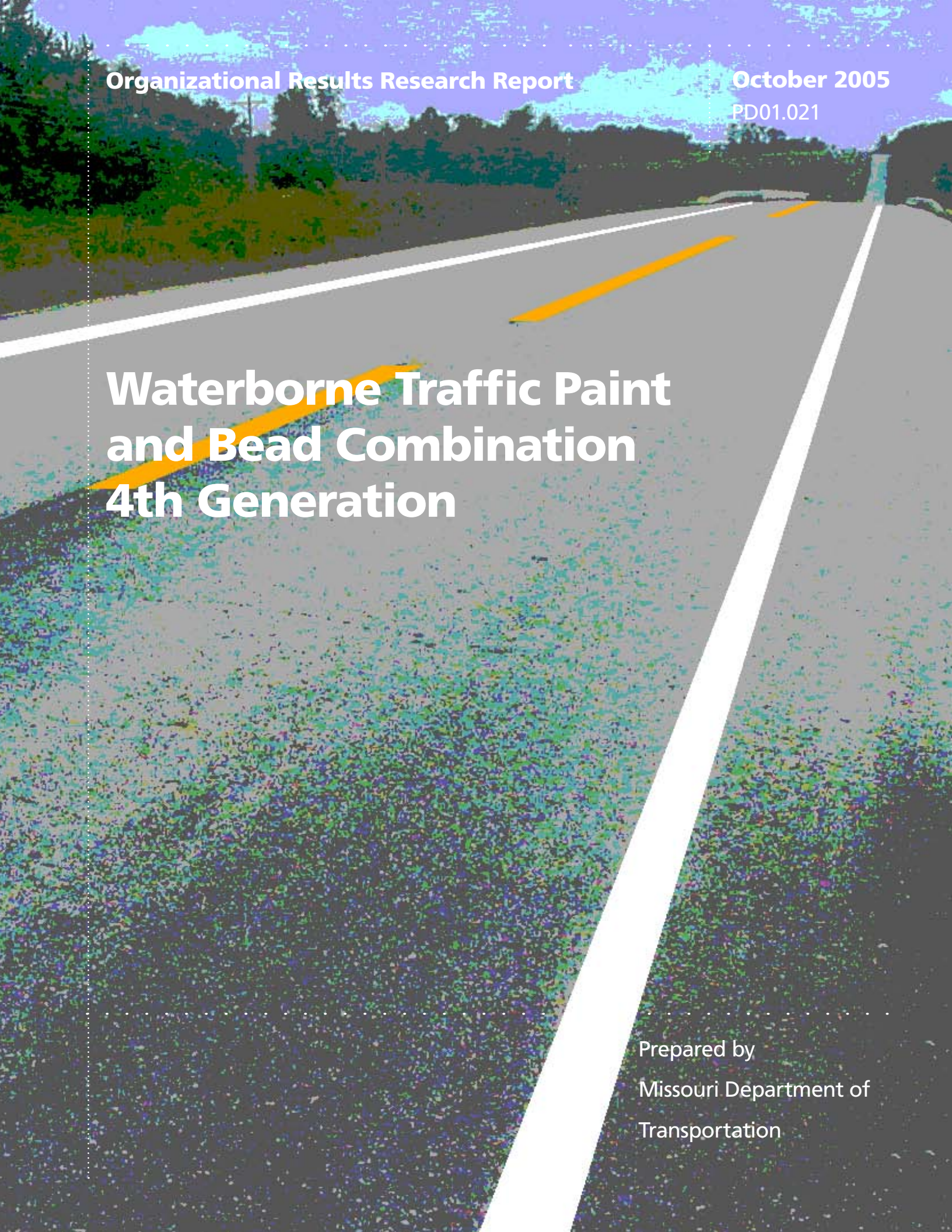


Organizational Results Research Report

October 2005

PD01.021

Waterborne Traffic Paint and Bead Combination 4th Generation

Prepared by

Missouri Department of Transportation

FINAL REPORT

OR 06-011

Waterborne Traffic Paint and Bead Combination 4th Generation

Prepared for the

Missouri Department of Transportation
Organizational Results

By

Daniel J. Smith, P.E.
Research and Development Engineer

Xinge (Julie) Yin
Senior Research and Development Assistant

October 2005

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. OR 06-011	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Waterborne Traffic Paint and Bead Combination 4th Generation		5. Report Date October 2005
		6. Performing Organization Code MoDOT
7. Author(s) Missouri Department of Transportation		8. Performing Organization Report No. OR 06-011/PD 01-021
9. Performing Organization Name and Address Missouri Department of Transportation Organizational Results P. O. Box 270-Jefferson City, MO 65102		10. Work Unit No. 11. Contract or Grant No.
12. Sponsoring Agency Name and Address Missouri Department of Transportation Organizational Results P. O. Box 270-Jefferson City, MO 65102		13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code MoDOT

15. Supplementary Notes
The investigation was conducted in cooperation with the U. S. Department of Transportation, Federal Highway Administration.

16. Abstract

The project analyzed the properties and durability of different bead and waterborne paint combinations placed on controlled test sections and MoDOT's district roadways. The waterborne paint and beads studied were 2nd generation and 4th generation resins and type 1 (small) and L (large) glass beads, respectively.

MoDOT is recommending the use of 4th generation resin white and yellow paint with PM beads on all minor and some major roadways. Due to previous studies, PM beads, sized between type 1 and L beads, will be used on all future MoDOT striping.

The 2nd and 4th generation resin white paint performed similarly on the minor roadways. A 17-mils of 2nd generation resin white paint with 10-lbs of PM beads is recommended to be studied to verify if 2nd generation resin white paint could provide 2-years of life for the minor roadways. If the 2nd generation resin white paint and PM beads system can provide a 2-year life, MoDOT could save over $1,000,000 every other year.

The 4th generation resin yellow paint showed that roadways below 400 AADT provided retroreflectivity level of 125 mcd for 2 winter seasons. MoDOT has over 15,000 miles of striping on the 400 AADT roadways and if the stripe could survive three years MoDOT could have cost savings between $2,500,000 and $5,000,000 over a 6-year period. MoDOT is recommended to collect a history of retroreflectivity on other districts to verify the 2-year and 3-year life on the 400 AADT roadways.

MoDOT should study increasing the proposed yellow bead and paint combination to provide 2-year life on MoDOT's 10,000 miles of striping on roadways ranging from 401-1000 AADT.

District should place a white and yellow line a minimum initial retroreflectivity reading of 350 mcd and 225 mcd to obtain 2-years of service life, respectively. The project provided retroreflectivity levels when districts should re-stripe the lines at levels 200 mcd for white lines and 175 mcd for yellow lines after one-year of life. MODOT should collect a history of readings from other districts to verify the initial and 1st year retroreflectivity levels.

Central Office Traffic division shall continue providing support to reduce the amount of re-striping. Over $700,000 per year of re-striping costs is due to unplanned maintenance work, location mistakes by the stripers, striping over adequate lines because they are not as bright as freshly painted failed lines.

The wet-night accident rates did not show that large beads would reduce wet-night accidents compared to small beads.

17. Key Words Retroreflectivity, waterborne paint, resin, generation, bead, type L, type 1, wet-night accidents	18. Distribution Statement No restrictions. This document is available to the public through National Technical Information Center, Springfield, Virginia 22161

19. Security Classification (of this report) Unclassified	20. Security Classification (of this page) Unclassified	21. No. of Pages 22 w/o Appendix	22. Price

Executive Summary

The project analyzed the properties and durability of different bead and paint combinations placed on controlled test sections and MoDOT's district 7 and 8 roadways. Waterborne paint with different resins was studied, which the resins were 2nd generation and 4th generation. Resin is the actual hardened material after the waterborne paint is dried. The project studied the type 1 (small) and L (large) glass beads. The glass beads provide the ability for the traveling public to see the paint stripe at night, which is commonly called retroreflectivity.

MoDOT has split the highway system into major and minor roadways and has recently implemented the use of 4th generation resin paint with PM beads on all minor and some major roadways. PM beads were decided to be used from previous MoDOT studies and because PM beads are between type 1 and L beads in size. Based on the results of this study, MoDOT's selection of using 4th generation resin paint is the proper choice, especially for yellow paint.

The 4th generation resin yellow paint on 400 AADT and lower roadways provided retroreflectivity levels over 125 mcd for 2 winter seasons. The 400 AADT roadways appear that District personnel should not have to spend resources checking the retroreflectivity readings for two years, if the paint is properly placed.

MoDOT has over 15,000 miles striping on the 400 AADT roadways and if the stripe could survive three years MoDOT could see a cost savings between $2,500,000 and $5,000,000 over a 6-year period. MoDOT should collect a history of retroreflectivity on 4th generation resin yellow paint in other districts to verify the 2-year and 3-year life on the 400 AADT roadways.

MoDOT should study increasing paint thickness and bead poundage of the proposed 20-mil 4th generation resin yellow paint and 10-lbs of PM bead combination to provide a possible 2-year life on MoDOT's 10,000 miles of striping on roadways ranging from 401-1000 AADT. If 2-year life were obtainable then MoDOT would save money and resources that are needed to monitor the retroreflectivity readings of the minor roadways.

The 2nd and 4th generation resin white paint performed similar on the minor roadways. MoDOT is resurfacing a vast percentage of the major roadways and the new pavement markings will consist of epoxy and tape. The current major roadways that will not be resurfaced will be striped with 4th generation resin white paint. The 4th generation resin white paint should be used until the mileage of MoDOT's in-house striping of major roadways is minimal. When that level is reached MoDOT should study the bead and paint combination of 17-mils of 2nd generation resin white paint with 10-lbs of PM beads to verify if 2nd generation resin white paint could provide 2-years of life for the minor roadways. If the 2nd generation resin white paint and PM beads system can provide a 2-year life, MoDOT could save over $1,000,000 every other year on the minor roadways.

The investigators provided a threshold of initial and 1st year service retroreflectivity level that should provide a two-year service life. At present, the recommended initial retroreflectivity level of 350 mcd for 4th generation resin white paint lines and 225 mcd for 4th generation resin yellow paint lines, which should provide a service life for 2-years. The project provided districts re-striping retroreflectivity levels of 200 mcd for 4th generation resin white paint lines and 175 mcd for 4th generation resin yellow paint lines after the 1st year of service. MoDOT should collect a history of retroreflectivity readings from other districts to verify or modify the initial and 1st year retroreflectivity levels.

Approximately $720,500 per year of re-striping costs is due to unplanned maintenance work, location mistakes by the stripers, and striping over adequate lines because they are not as bright as freshly painted lines. Central Office Maintenance and Traffic divisions should continue providing support to district Maintenance and Traffic personnel to implement best practices to reduce re-striping of adequate line on MoDOT roadways.

For comparison of type 1 (small) versus type L (large) beads, different wet-night accident rates were studied by splitting the accident rates into seasons, which range from May to October and November to April. The wet-night accident rates did not show large beads would reduce wet-night accidents compared to small beads.

Table of Contents

List of Figures

List of Tables

Introduction

Since 1994, the Missouri Department of Transportation (MoDOT) paint stripe policy has been acrylic waterborne paint consisting of 14 to 16-mils of 2nd generation resin paint with 8 lb/gal of type 1 beads. In 2003, District 7 started applying 20-mils of 4th generation resin waterborne paint with 12-lbs of type L beads on an experimental basis while the rest of the state continued to apply 2nd generation resin paint with type 1 beads. (Reference 1, 2, 3)

In Missouri, the different types of resin used in the paint are designated as generations. MoDOT's distinction of the resin generations is different in other states. The MoDOT generation titles are designated in table 1 with the resin name, resin manufacturer, recommended paint thickness and bead application rates, and expected durability.

Table 1: Manufacturer's Waterborne Paint Recommendations

Generation (MoDOT title)	DOW (Resin)	Rohm Haas (Resin)	Rec. Paint Thick (mil)	Rec. Bead Type	Rec. Bead App. (lbs)	Manufacturer Relative Expected Durability (year)
2	DT 211	E-2706	14-16	1	6-8	1
3	DT 250	E-3427	14-16	1	6-8	1+
4	DT 400	HD-21	22-30	L	10-12	2

In general, the waterborne paint with 2nd generation resin lasts an average of 1-year and 4th generation resin should last 2-years. The life of the paint varies due to the following reasons: snowplowing, traffic volume, proper paint installation, proper paint thickness and bead amount, quality of material underneath the paint stripe (older pavement marking material, asphalt, concrete), crack sealing over stripe, pavement repair, etc.

As noted, MoDOT uses the Type 1 and L beads or also known as small and large beads, respectively. The glass beads provide the driver the ability to see the paint lines at night, which is commonly called retroreflectivity. (Ref. 4)

In 2003, MoDOT management decided that the department should have a consistent in-house pavement-marking program for the entire state. The "Waterborne Traffic Paint and Bead Combination 4th Generation" project was initiated to provide the best bead and paint combination for MoDOT. The project compared different bead and paint combinations in the following scenarios: 1) controlled test sections located in District 7 and 2) selection of District 7 roadways using 20-mils of 4th generation resin paint with 12-lbs of type L beads and District 8 roadways using 15-mils of 2nd generation resin with 8-lbs of type 1 beads.

In April 2005, MoDOT's "Tracker: Measures of Departmental Performance" was published. The "MoDOT: Tracker is a tool to assess how well we deliver services and products to our customer."(1) Within the "Tracker" are 18 tangible results that "our customers expect to see as we fulfill our mission."(1). Each tangible result has performance measures, which the performance measures are designed to help MoDOT focus on successfully achieving the 18 results. Under the tangible result titled "Roadway Visibility" is a measure titled "Percent of Stripes that meet our Customers' Expectations". Each year the "Percent of Stripes that meet our

Customers' Expectations" measure will monitor the percentage of the striping mileage that is above the retroreflectivity benchmark of 150 mcd for white stripes and 125 mcd for yellow stripes. (Ref. 5)

In June 2005, MoDOT's Chief Engineer accepted the "Roadway Visibility Direction" for implementation. (2) The MoDOT highway system has been separated into two different categories: "Minor and Major Roads". The "Roadway Visibility Direction"(2), pertaining to waterborne paint, is as follows:

- Minor Roads will be striped with 20 mils of 4th generation paint with 10 lbs of PM beads, four-inches wide every other year.
- Major Roads, without a new surface, will be striped with 20 mils of 4th generation paint with 10 lbs of PM beads, 6-inches wide edge line and 4-inch wide centerlines every year.

The "Roadway Visibility Direction" recommendation of 20-mil of 4th generation resin paint with 10 lbs of PM beads was based on 1st year preliminary data from the "Waterborne Traffic Paint and Bead Combination 4th Generation" project. (Ref. 6,7)

Provided that preliminary data from this project has been implemented, the following objectives remain:

1. What are the reasons to Districts re-stripe and MoDOT should review maintenance activities.
2. What retroreflectivity threshold should districts re-stripe to maintain future customer satisfaction?
3. Is the "Roadway Visibility Direction" strategy obtainable for MoDOT?

Study Approaches

The "Waterborne Traffic Paint and Bead Combination 4th Generation" project compared 2nd and 4th generation paint resins, Type 1(small) and L(large) beads, and varied paint thickness. Test sections were selected on new asphalt (NA), old asphalt (OA), and old concrete (OC). The three test sections had longitudinal lines placed by District 7 stripers. Each test section was 8 miles in length, which consisted of eight different bead and paint combinations creating eight one-mile long test lines. Even though the test sections were located at three different sites within district 7, the eight bead and paint combinations within a test section were affected by the same traffic volumes, treated by the same maintenance crews, and exposed to the same weather conditions. A third party laserlux machine collected the retroreflectivity readings. The retroreflectivity readings were taken in the fall 2003 (initial placement), spring 2004 (after 1st winter season), fall 2004 (one full year), and spring 2005 (after 2nd winter season). The typical 8-mile test section is located in the work plan on page A4 in Appendix A titled "Evaluation of Waterborne Traffic Paint and Bead Combination". For the report, the three test sections locations will be referred to as "test sections".

In early 2004, a decision was made to compare a selection of District 7 roadways using 20-mils of 4th generation resin paint with 12-lbs of type L beads and District 8 roadways using 15-mils of

2nd generation resin with 8-lbs of type 1 beads. MoDOT wanted to study the two different bead and paint combinations under real world conditions, for example, roadways with different AADT's and roadway surfaces, new stripe placed on old stripe, different maintenance snowplowing procedures and equipment, different stripers placing the material, etc. Each district provided over three hundred miles of yellow and three hundred miles of white striping. The districts placed the striping in the 2003 season. District 7 and 8 were selected since normally the weather conditions (winter storms) are similar. The guidelines, that district 7 and 8 used to identify the study lines locations, are located in appendix B titled "The 2nd and 4th Generation Paint Snowplowing Damage Issue".

Initial 2003 retroreflectivity readings were not available since the decision to have a district comparison was made in early 2004. The first retroreflectivity readings were performed in Spring 2004 (after 1st winter season), fall 2004 (full year), and spring 2005 (after 2nd winter season). A third party laserlux machine collected the retroreflectivity readings.

The district 7 and 8 study line data analysis is based on the following criteria:

1. Spring 2004 data has all the selected roadway retroreflectivity readings. The percentage of roadway mileage that was below the benchmark of 125-mcd for yellow and 150-mcd for white striping was based on all 2004 roadway mileage.
2. Spring 2005 data consists of all the roadways that were not re-striped in 2004. Roadway study lines that were re-striped based on other criteria than the "Percent of Stripes that meet our Customers' Expectations" retroreflectivity benchmark of 125-mcd for yellow and 150-mcd for white striping were not used in the report. The Spring 2005 data is based on the remaining un-striped roadways. Thus the percentage of 2005 roadway study lines cannot be calculated with 2004 study line data.

Results

In April 2005, MoDOT decided to work toward maintaining a certain level of retroreflectivity, and the benchmark has been set as 125-mcd yellow and 150-mcd white. The following discussion on test section lines and District 7 and 8 study lines, is based on these new standards.

Test Section Lines - The bead and paint combination in the three test locations of new and old asphalt and old concrete were combined and averaged into one graph. The results for each individual test section are located in appendix C titled "MoDOT Test Sections".

The bead and paint combinations in the test sections are designated by the following titles: T-4-28-L(12#), T-2-15-1(8#), etc. The meaning of the bead and paint titles is located in table 2.

Table 2: Test Section Bead and Paint Combination Explanation

Title	Description
T	Test Section
2 or 4	2nd or 4th generation paint resin
15, 17…28	Paint thickness in mils
1 or L	Small or Large bead types
(8,10,12#)	Pounds of beads used in the stripe

District 7 and 8 Study Lines – For clarity, the retroreflectivity reading analysis compared Spring 2004 and Spring 2005 data, with the break out between major and minor roadways. However, from Spring 2004 to Spring 2005, some of the study lines were re-striped. As the result, the Spring 2005 data is based on the remaining roadways.

One aspect that stands out between MoDOT highway system and other state highway systems is the amount of lower Annual Average Daily Traffic (AADT) roadways. MoDOT maintains 32,000 miles of roadways, which 57% (18,500 miles) are less than or equal to 1000 AADT. In Missouri, the striping policy for roadways less the 1000 AADT states that white edge lines are not mandatory but yellow striping is mandatory.

Besides the lower traffic volume, these roadways are normally snowplowed less compared to the higher AADT roadways. With less traffic wear and snowplowing, the striping in theory should last longer. Thus this group of roadways was analyzed separately. In the study, the roadways less than 1000 AADT were split into two categories:

- Less than or equal to 400 AADT (centerline only)
- 401-1000 AADT levels (centerline, possible edge line).

The 400 AADT and 401-1000 AADT roadway centerline miles and calculated striping mileage are located in table 3. Due to the different passing and no-passing markings for a roadway, a multiplier between 1.25-1.50, provided by Maintenance division, was used to calculate the total striping mileage.

Table 3: Calculated Striping Mileage for <400 AADT and 401-1000 AADT Roadways

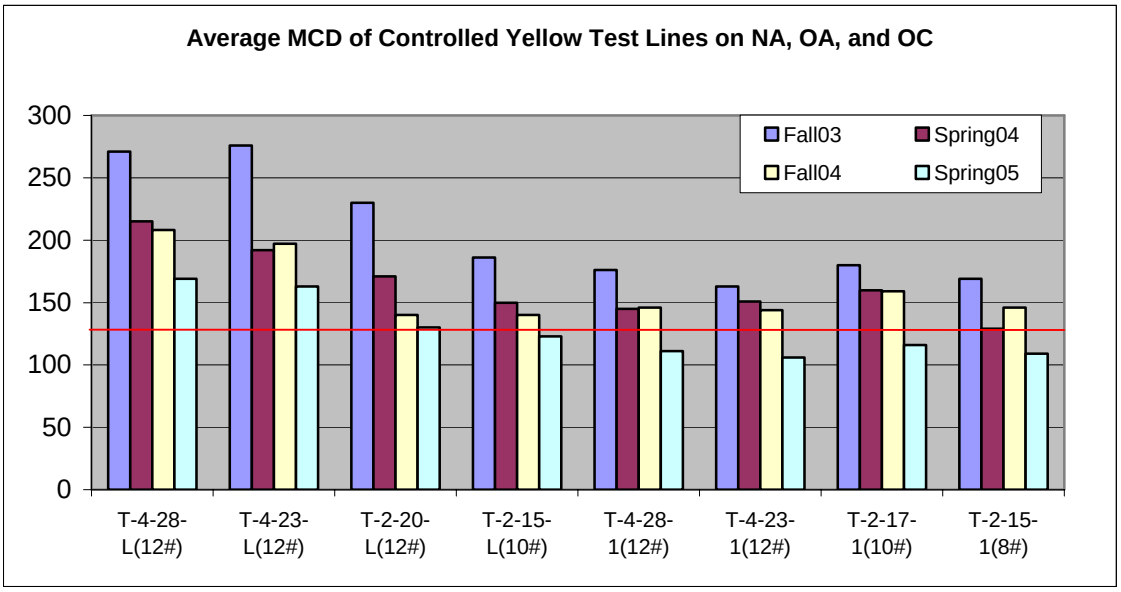
Roadway AADT Category	Centerline Miles	Calculated Striping Miles
< 400	10,822	15,000
401 – 1000	7,752	10,000

Performance of Yellow Paint

District 7 Test Section Lines (Yellow Paint)

As shown in figure 1, three bead and paint combinations were above the initial minimum retroreflectivity standard of 225 mcd as stated in the 2004 Missouri Standard Specification for Highway Construction. After the 1st season, all the bead and paint combinations were above the "Customer Expectation" measure of 125 mcd.

Figure 1: Average Test Sections Retroreflectivity Readings for Yellow Lines.



Four yellow bead and paint combinations were above or within 2 mcd of the designated yellow stripe measure of 125 mcd after two winter seasons, as shown in table 4.

Table 4: Yellow Test Section Bead and Paint Combination greater 125 mcd

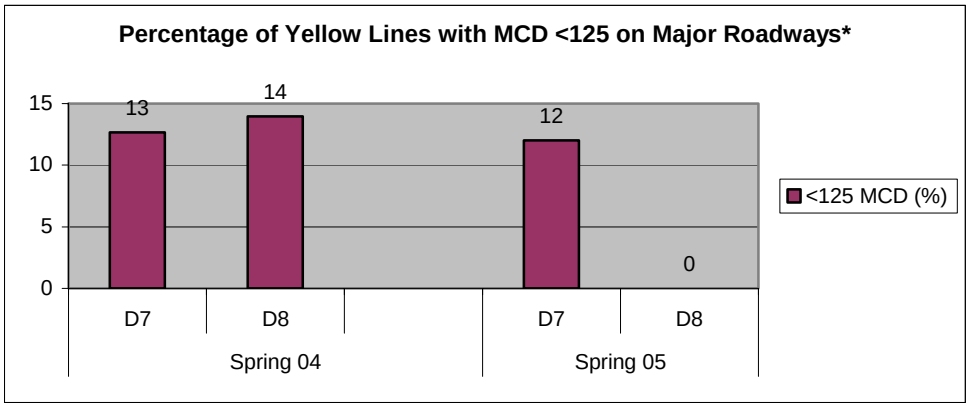
Test Combination >125 mcd	Retroreflectivity Reading (mcd)
T-4-28-L(12#)	169
T-4-23-L(12#)	163
T-2-20-L(12#)	130
T-2-15-L(10#)	123

The combinations with large beads performed well, among them T-4-28-L(12#) and T-4-23-L(12#) performed the best. However the 2nd generation combination of T-2-20-L(12#) survived two winters. The 20-mil thickness may be a concern because of possible chipping of the material. The 2nd generation paint is normally recommended for thin application rate of 14-16-mils.

District 7 and 8 Major Roadways (Yellow Paint)

The district study line were placed in 2003, but due to later planning the first reteroreflectivity readings were taken in spring 2004. As shown in figure 2, the yellow stripe performance between the two generations was similar, especially the first season. During the second season 4th generation had a higher percentage of poor performance lines, however, the second season had a low amount of major roadway miles for comparison, which made a recommendation inconclusive.

Figure 2: Percentage of Yellow Lines with MCD <125 on Major Roadways

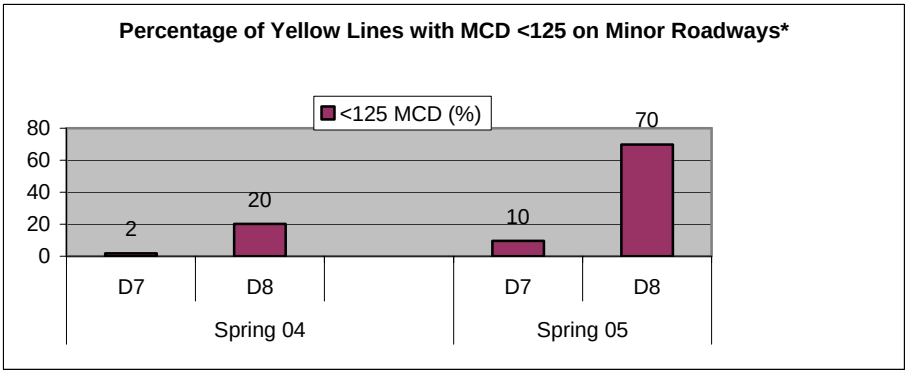


*District 7 – Spring 04 – 31.62 miles and Spring 05 – 22.50 miles
*District 8 – Spring 04 – 80.20 miles and Spring 05 - 25.10 miles

District 7 and 8 Minor Roadways (Yellow Paint)

As shown in figure 3, District 7 lines performed well through the first year with only 2% below 125 mcd. The District 8 lines had 20% below 125 mcd. In the second year, District 8 had 70% of the lines below 125 mcd, while District 7 had only 10% of the roadways below 125 mcd. According to these numbers, 4th generation yellow paint performed better than 2nd generation yellow paint.

Figure 3: Percentage of Yellow Lines with MCD <125 on Minor Roadways

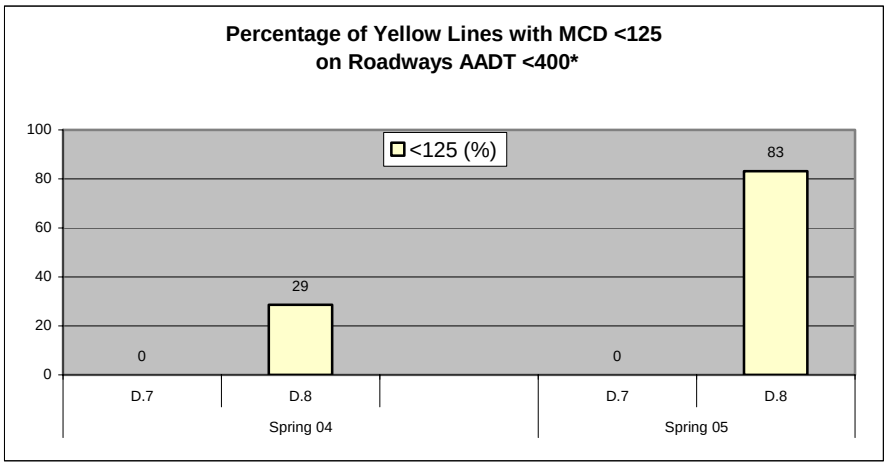


*District 7 – Spring 04 – 320.78 miles and Spring 05 – 210.30 miles
*District 8 – Spring 04 – 296.60 miles and Spring 05 – 219.50 miles

District 7 and 8 Minor Roadways w/less than 400 AADT (Yellow Paint)

As shown in figure 4, District 7 had 0% of the roadways under 125-mcd for both years. District 8 had less than a third of the roadway below 125-mcd in Spring 2004, but in Spring 2005 the percentage increased to 83%. The 4th generation yellow paint with large beads performed exceptionally well on the roadways with AADT below 400.

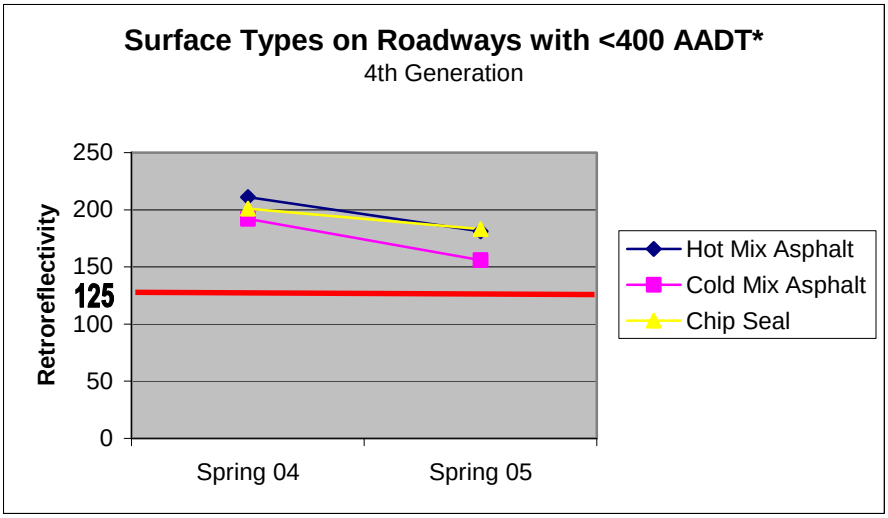
Figure 4: Percentage of Yellow Lines with MCD <125 on Roadways AADT <400



*District 7 – Spring 04 – 62.23 miles and Spring 05 – 62.23 miles
*District 8 – Spring 04 – 106.40 miles and Spring 05 - 44.00 miles

Since the 400 AADT roadways did not lose striping through the two years of study, the 400 AADT roadways were categorized into surface types. As located in figure 5, the chip seal and hot mix asphalt surfaces had retroreflectivity readings of 183 mcd and 181 mcd, respectively. The cold mix asphalt surface had retroreflectivity reading of 156 mcd.

Figure 5: Retroreflectivity Readings for Surface Types on Roadways with <400 AADT

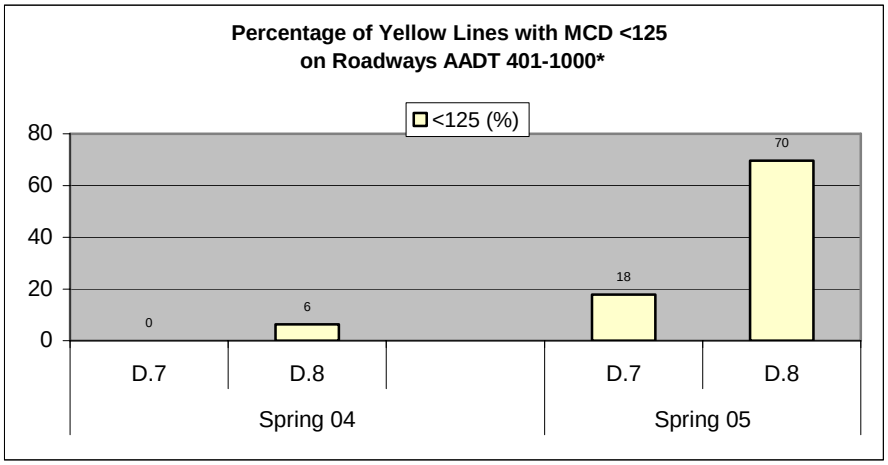


*Chip Seal Mileage – 24.0 miles, Cold Mix – 33.0 and Hot Mix – 5.2 miles

District 7 and 8 Minor Roadways w/ 401-1000 AADT (Yellow Paint)

District 7 and 8 yellow striping performed well the first year that had 0% and 6% study lines below 125-mcd, respectively. The next season, District 8 had 70% while District 7 had only 18% of the remaining study lines below 125-mcd, as shown in figure 6. Again, the numbers showed that the 4th generation yellow paint performed much better than 2nd generation on low AADT minor roadways.

Figure 6: Percentage of Yellow Lines with MCD <125 on Roadways AADT 401-1000

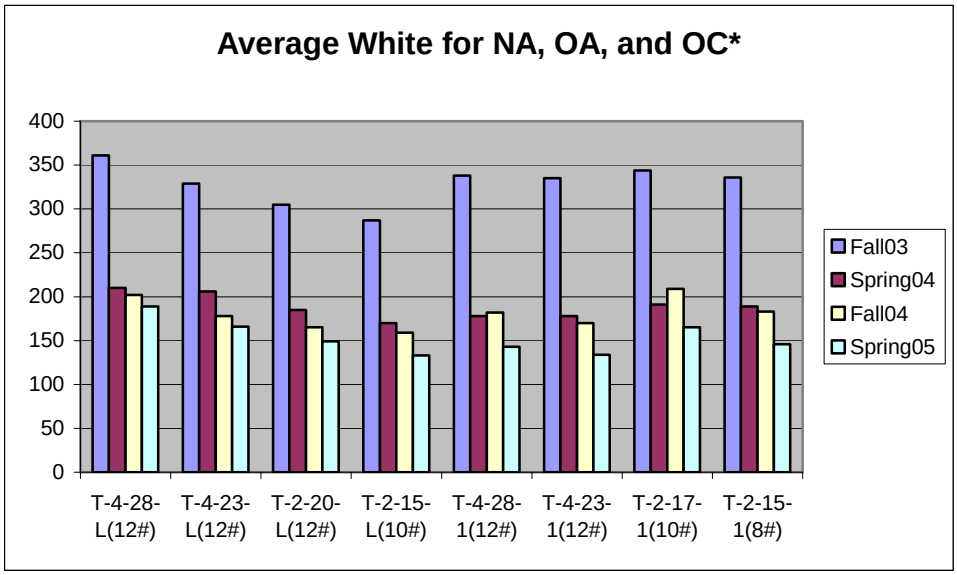


*District 7 – Spring 04 – 142.56 miles and Spring 05 – 95.10 miles
*District 8 – Spring 04 – 92.60 miles and Spring 05 – 92.60 miles

Performance of White Paint

District 7 Test Section Lines (White Paint)
As shown in figure 7, seven bead and paint combinations were above the 2004 Missouri Standard Specifications for Highway Construction initial retroreflectivity minimum of 300 mcd. After one season all the bead and paint combinations were above the "Customer's Expectation" measure of 150 mcd.

Figure 7: Average Test Sections Retroreflectivity Readings for White Lines.



After the second winter season, four bead and paint combinations were very near or above the "Customer Expectation" benchmark for white stripe of 150 mcd, as shown in table 5. Two of the

four were 4th generation resin paint with large beads. An interesting note is that the T-2-17-1(10#), which has 2-mils of paint and 2-lbs of beads more than the MoDOT standard T-2-15-1(8#), performed as well as the T-4-23-L(12#).

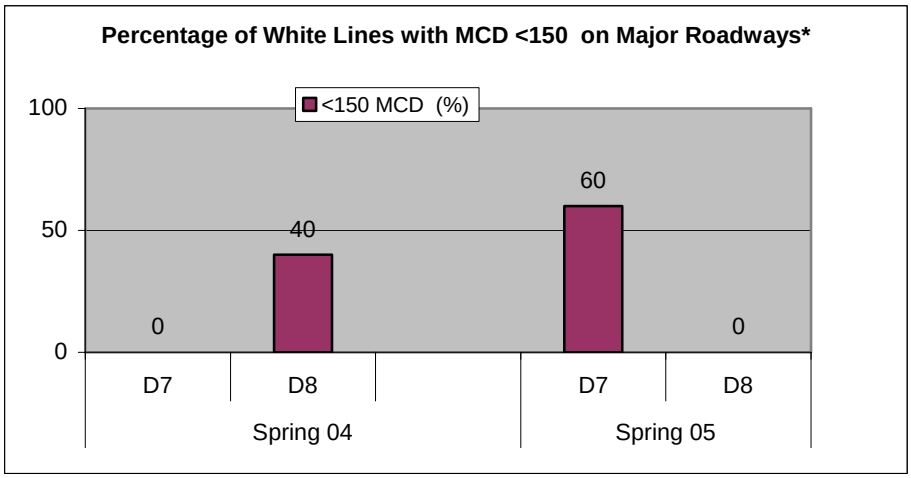
Table 5: White Test Section Bead and Paint Combination greater 150 mcd

Test Combination >150 mcd	Retroreflectivity Reading (mcd)
T-4-28-L(12#)	189
T-4-23-L(12#)	166
T-2-20-L(12#)	149
T-2-17-1(10#)	165

District 7 and 8 Major Roadways (White Paint)

As shown in the figure 8, District 8 (2-15-1(8#)) had 40% of the district study lines below 150-mcd after one season, while District 7 (4-20-L(12#) had 0% below 150-mcd. The second season on the remaining lines, District 7 had 60% and District 8 had 0% below 150-mcd. The districts did not have a large amount of major roadway mileage as compared to minor roadways for the study line data, coupled with the mixed performance index as shown in graph 8. Thus a conclusion could not be reached of which retained better retroreflectivity, the 4th or the 2nd generation resin.

Figure 8: Percentage of White Lines with MCD < 150 on Major Roadways

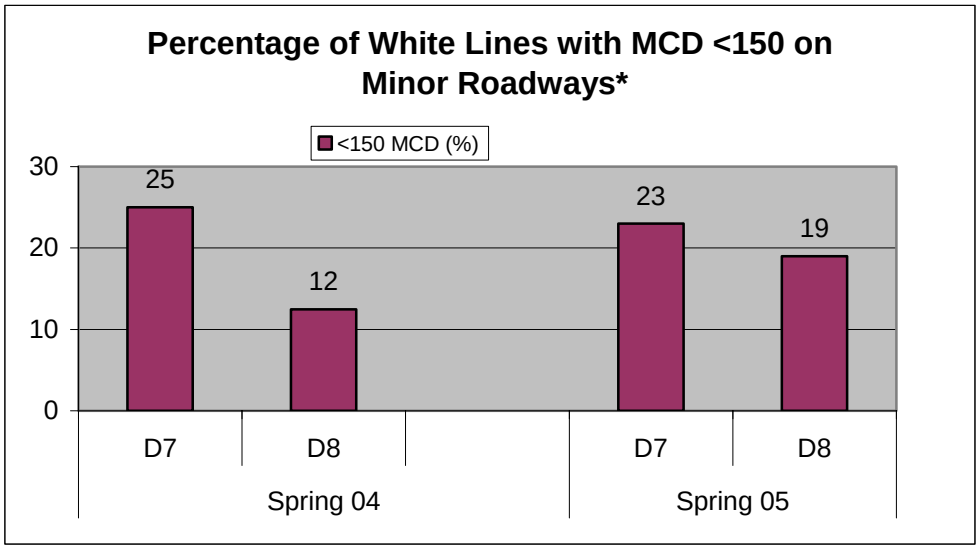


*District 7 – Spring 04 – 71.60 miles and Spring 05 – 63.60 miles
*District 8 – Spring 04 – 169.40 miles and Spring 05 - 25.10 miles

District 7 and 8 Minor Roadways (White Paint)

As shown in figure 9, during the first year, 25% of District 7 and 12% of District 8 study lines were below 150 mcd. The second year, 23% of District 7 and 19% of and District 8 study lines were below 150 mcd. The minor roadway white study lines did not show a definite conclusion on which one performed better, the 4th generation or 2nd generation.

Figure 9: Percentage of White Lines with MCD < 150 on Minor Roadways

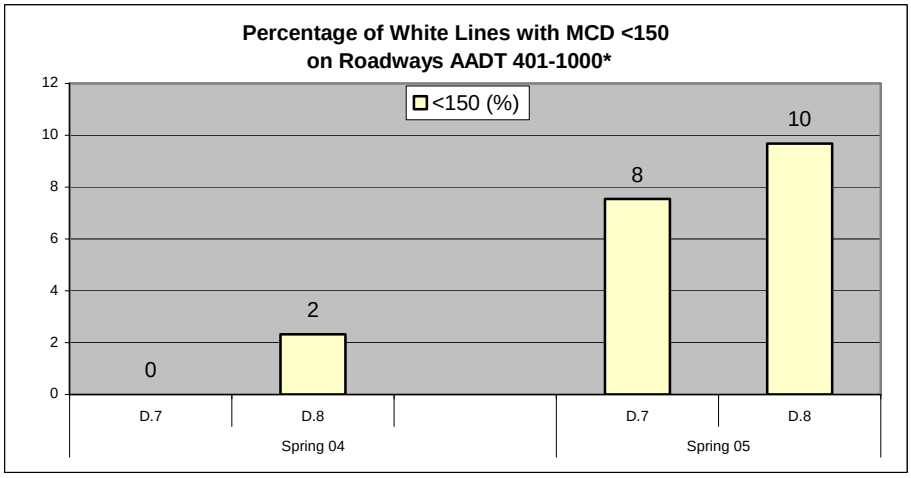


*District 7 – Spring 04 – 225.60 miles and Spring 05 – 96.30 miles
*District 8 – Spring 04 – 168.60 miles and Spring 05 – 142.60 miles

District 7 and 8 Minor Roadways w/ AADT 401-1000 (White Paint)
Normally, roadways less than 1000 AADT do not have white edge lines, but districts do have the decision to stripe the edge lines. The mileage of edge line striping is low compared to the entire 401-1000 AADT striping program.

Again, the white study lines have shown the two districts performed similar in percentage below 150-mcd, as shown in figure 10. The first season, district 7 and 8 had 0% and 2% of study lines below 150-mcd, respectively. The remaining lines in Spring 2005 showed that district 7 and 8 performed similar to each other with 8% and 10% study lines below 150-mcd, respectively.

Figure 10: Percentage of White Lines with MCD <150 on Roadways AADT 401-1000



*District 7 – Spring 04 – 38.80 miles and Spring 05 – 23.20 miles
*District 8 – Spring 04 – 46.40 miles and Spring 05 – 46.40 miles

Wet Night Accidents: Type L and Type 1 Beads

MoDOT districts have used two types of beads, which District 5 and 7 used type L beads and the rest of the state used type 1 beads. District 5 and 7 have used the type L beads for their concern of wet-night traveling and the larger beads help reduce paint track time.

Previous studies, as sited in "Roadway Visibility Direction", have compared the ten district wet-night accident rates (2). The wet-night accident rates were based on 5 years of information (1998-2002) for all 10 districts and based on the whole year from January-December. The findings showed that District 5 and 7 were ranked in the middle of the districts and could not support the theory of reduced wet-night accidents associated with type L beads.

One of MoDOT's Tracker Roadway Visibility measure is "Rate of Wet Weather Crashes". Even though District 5 and 7 fell in the middle of the districts for the statewide wet-night accident data, the investigators decided to analyze the wet-night accident rates split into seasons. The data separated the months from May to October and November to April. The months from May to October should show wet-night accident rates based on better quality lines and the months from November to April should show wet-night accident rates based on winter concerns.

MoDOT's Transportation Management System provided the information for the project. An explanation of the Wet-Night Accident criteria is located in Appendix D titled "Wet-Night Accident Information". Five Wet-Night Accident types were analyzed and the results are summarized in Table 6. See Appendix E titled "Statewide Performance of Type 1 and L Beads" for the graphs.

Table 6: Highest Wet-Night Accident Rate District Leaders*

Wet-Night Accident Type	**May to October**	**November to April**
Total	District 8	District 6
Head-On	District 6	District 6
Fixed Object	District 5	District 7
Out-of-Control	District 5	District 7
Sideswipe	District 5	District 6

*Accident Rate yields a result in accidents per hundred million vehicle miles traveled (HMVMT).

- Total Accident Rate – District 8 had the highest wet-night total accident rate for the months of May to October. District 5 was above the state average and district 7 was below the state average, but neither were the highest or the lowest. District 6 had the highest for November to April. District 5 and 7 were below the state average for the month of November to April, but still were not the lowest.
- Head-on Accident Rate – District 6 had the highest wet-night Head-on accident rates for May to October and November to April. District 5 and 7 were slightly above the state average for the months of May to October. District 5 was below the state average for the months of November to April. District 7 was above the state average.
- Fixed-Object Accident Rate – Districts 5 had the highest accident rates for the month of May to October and District 7 was below the state average. The months from November

to April, District 7 had the highest accident rates and District 5 was below the state average.

- Out-of-Control Accident Rate – District 5 had the highest accident rate for the months of May to October and District 7 was below the state average. District 7 had the highest accident rate for November to April and District 5 was below the state average.
- Sideswipe Accident Rate – District 5 had the highest accident rate from the months of May to October and District 7 was below the state average. District 6 had the highest accident rate for the month of November to April. District 7 was above the state average and District 5 was below the state average.

As with any accident information, the reasons for accidents cannot be contributed to one variable such as glass bead sizes. Wet-night accidents could be caused by numerous reasons. However, it is obvious that the type L bead districts did not show a decrease of accident rates as compared to other districts.

Discussion

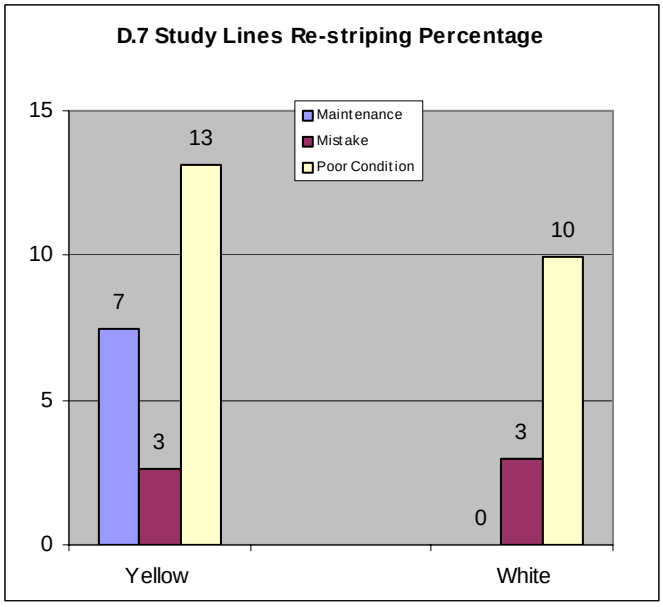
Re-striping and Maintenance Activity

In the past, MoDOT's policy had been to re-stripe roadways every year regardless if the lines provided adequate delineation. Starting since 2003, districts have been trying to reduce re-striping based on the conditions of the stripe. A series of criteria were defined in the 2003 "Evaluation of Laserlux Readings" guideline provided by Maintenance Division, which is located in Appendix F. The criteria were a combination of retroreflectivity reading and subjective rating, though the "Evaluation of Laserlux Reading" guidelines did not define how to give a subjective rating. District 7 created its own "Subjective Rating for Stripe" criteria to possibly clarify this system, which is located in Appendix G.

During 2003-2004 striping season, a portion of the District 7 and 8 study lines were re-striped based on these criteria. However, re-striping did occur due to other reasons. Within the scope of District 7 study lines, investigators asked the striping crew to identify the lines being re-striped from Spring-Fall 2004, and the reasons for re-striping. The re-striping reasons consists of the following: 1) the lines were in poor condition, 2) the lines were not aesthetically pleasing, 3) maintenance work obliterated the lines, 4) lines re-striped by mistake.

Figure 11 shows the percentage of different re-striping scenarios, under the titles of maintenance, mistakes, and poor condition ("poor condition" consisted of lines in poor condition and lines re-striped due to aesthetic concerns). The percentage of District 7 study lines that were not re-striped (77% for yellow and 87% for White), is not shown in the figure.

Figure 11. District 7 Study Lines Re-striping Percentage



Maintenance Concerns - The maintenance activities that can obliterate the roadway striping consist of crack-sealing, patchwork, leveling courses, etc. District Traffic personnel stated that they would contact the district Maintenance personnel and ask which roadways would be worked on during the striping season. The stripers would not stripe a roadway that would be worked on until later the same season after the maintenance work is complete. However, the stripers are concerned when maintenance forces will do work on unplanned roadway work. Then the stripers will have to re-stripe brand new lines. The unplanned roadway work, as stated by district Traffic personnel, are predominately not emergency concerns.

When the investigation on District 7 and 8 study lines were initiated, traffic personnel were asked to pick roadways that would not need maintenance work for couple of years. However during summer 2004, District 7 Maintenance forces did some type of maintenance work on the roadways, which required 7% of the yellow study lines to be re-striped (white study lines were not affected). The principles investigators contacted MoDOT's Traffic division to verify if 7% of re-striping due to maintenance work was realistic.

MoDOT's Traffic division has been keeping track of the amount of re-striping due to maintenance activities over the past two years. District Maintenance and Traffic divisions have been working on reducing the amount of re-striping, as shown in table 7.

Table 7. MoDOT Highway System Re-striped Due to Maintenance Activities

Year	Percent Re-striped (%)	Miles of Re-striping
2003	4.03	3125
2004	3.19	2366

Using 2366 miles, statewide it costs MoDOT $720,500/year (based on 20-mils of 4th generation resin yellow paint with 10-lbs of PM beads) to re-stripe due to maintenance activities, which the

calculations are located in appendix H titled "2004 MoDOT Re-striping Pavement Marking Lines Due to Maintenance Activities". Continued communication between district maintenance and traffic forces will be critical since MoDOT is expecting two-years of life from the more expensive 4th generation resin paint and PM bead combination.

Re-striping Due to Mistakes - District 7 noted the locations that were re-striped because of mistakes in defining the proper striping location. Mistakes accounted for 3% of the yellow study lines and 3% of the white study lines. Traffic division was not able to provide a number for re-striping due to mistakes, but coordination with the stripers should also be constantly monitored.

Re-striping due to Poor Condition - The lines re-striped under "poor condition" title, included 1) lines with poor quality and low retroreflectivity readings, and 2) lines aesthetically not pleasing. District 7 re-striped 13% of the yellow study lines and 10% of the white study lines due to poor condition, but did not breakout between poor condition and aesthetic reasons.

Paint chipping is an aesthetic and line quality reason for re-striping. Roadways may have adequate retroreflectivity but the line may have paint chipping. In the future, a consistent policy on missing material should be provided to make a re-striping decision.

A common practice of districts is when a poor quality line is re-striped the other adequate stripes close by are also re-striped. The reason is the adequate old lines are not as bright as the freshly re-striped line. With the cost of the 4th generation paint MoDOT should discuss dropping the practice of re-striping an adequate line just to make all the lines look the same age.

Retroreflectivity Threshold for District Re-striping Strategy

With MoDOT changing their policy from striping every year to every other year, the stripers want to have a retroreflectivity threshold for re-striping, or at what level should the retroreflectivity be, so next year the line will be above the performance benchmarks established to meet customers expectations. The investigators analyzed two sets of data on the 4th generation paint, the controlled test section data and District 7 study line data to help identify striping performance trends.

Controlled Test Sections - The average retroreflectivity drops were calculated, between initial reading of Fall 2003 to Spring 2004, and between Spring 2004 and Spring 2005. The numbers are located in table 8, and more details on the calculation can be found in Appendix I titled "Test Section MCD Drop".

Table 8: Average MCD Drop on Controlled Test Lines

Line Type	Fall 2003 to Spring 2004 MCD Drop	Spring 2004 to Spring 2005 MCD Drop
Yellow	46	38
White	148	35

District 7 Study Lines - District 7 study line retroreflectivity readings were analyzed and the information obtained is located in table 9. The information calculated was average mcd, standard deviation, median mcd, upper limit mcd, and lower limit mcd based on Spring 2004 retroreflectivity readings.

Table 9: Different Methods Estimating Retroreflectivity MCD Threshold for Re-striping

Method	Lines	Average MCD	STDEV	Median MCD	Upper MCD	Lower MCD
1	Yellow	160	18	159	183	139
	White	181	32	184	229	141
2	Yellow	195	28	199	255	140
	White	184	25	190	224	129
3	Yellow	177	28	166	215	143
	White	186	25	199	224	145

The investigators used three methods to obtain the information in table 9.

Method 1: All lines below the performance measurements in Spring 2005 were cross-referenced with Spring 2004 readings. The statistics in table 9 are calculated from Spring 2004 lines that measured lower than 125-mcd and 150-mcd retroreflectivity reading in Spring 2005.

Method 2: All lines above the performance measurements in Spring 2005 were cross-referenced with Spring 2004 readings. The statistics in table 9 are calculated from Spring 2004 lines that measured higher than 125-mcd and 150-mcd retroreflectivity reading in Spring 2005

Method 3: Concern was stated that Method 2 could provide a more conservative number since there could be many study lines with very high readings, which would raise the average higher. Method 3 is similar to Method 2, except a range of mcd was selected above 125-mcd and 150-mcd retroreflectivity levels. The Spring 2005 ranges that were selected are 125-140 mcd for yellow lines and 150-170 mcd for white lines.

The initial retroreflectivity readings were not available on District 7 study lines. A mcd drop could not be calculated from Fall 2003 to Spring 2004.

Recommended Threshold Retroreflectivity Numbers - Reviewing the information in Table 8 and 9, which detailed reasoning is located in Appendix J titled "Recommended Threshold Retroreflectivity Number", the investigators recommended the numbers in Table 10 to be used to produce a 2-year service life, with the confidence that the lines will still perform above the minimum retroreflectivity standards during the 2nd-year service. For the yellow lines, an initial 225-mcd (based on MoDOT Specification Minimum), and the 1st year level of 175-mcd should provide a 125-mcd yellow line into the 2nd year. On the white lines, an initial 350 mcd, and the 1st year level of 200-mcd should provide a 150-mcd white line into the 2nd year.

Table 10: Retroreflectivity Level for Re-striping White and Yellow Paint

Color	MoDOT Spec. Min. (mcd)	Initial Reading (mcd)	1st Year Reading (mcd)	2nd Year Reading (mcd)
White	300	350	200	150
Yellow	225	225	175	125

The MoDOT initial retroreflectivity minimum specification of 300 mcd for the white line was based on several surrounding state DOT initial retroreflectivity minimum specifications. The calculated minimum initial reading of 350 mcd appears conservative as compared to the minimum of 300 mcd. MoDOT should obtain a representative history of the mcd drop on other

district roadways to verify and provide stripers with a standard initial and 1st year striping level for white lines.

Statewide Striping Strategy

MoDOT "Roadway Visibility Direction"(2) proposes: "The major roadways, without a new surface, will be striped every year with 20 mils of 4th generation paint with PM beads. The minor roadways will be striped with 20 mils of 4th generation paint with PM beads every other year." This proposal was partly based on first year preliminary findings from this study.

For the report, the investigation used the assumption that the new MoDOT recommendation of 4-20-PM(10#) would provide the same life as 4-20-L(12#), because of the same paint mil thickness and the PM beads would have a higher percentage of embedment than the type L beads. As with any changes to a studied system, a history should be collected on the proposed 4-20-PM(10#) system in the future.

With the continuation of the study, more interesting and worthwhile topics are brought out. The discussions in this section will cover the future striping performance with regards to the Tracker benchmarks, possible ways to improve the proposed striping program.

Cost Effectiveness

Major Roadways

Yellow Lines – On the major roadways, District 7 and District 8 yellow study lines data showed that the stripe performance between the two generations was similar, however, the use of 4th generation paint on major roadways would be questionable because of its higher cost. Because these lines are to be replaced every year, use of 2nd generation paint with small beads would be more cost effective.

White Lines – The controlled test section showed the 4th generation paint with large beads performed over the 2nd generation paint. MoDOT's choice to stripe the major roadways with 4-20-PM(10#) every year was the proper selection.

Minor Roadways

Yellow Lines on Minor Roadways w/less than 400 AADT - On the District 7 minor roadways with AADT below 400, the study lines had a zero percentage below 125-mcd after two winters, and there were no re-striping on these lines between two seasons. The average retroreflectivity still maintained 169 mcd in Spring 2005. These stripes could possibly last a third year, if slightly thicker paint and heavier bead application are used. If a third year is obtained, MoDOT could have a potential of saving money by changing from a 2-year cycle to a 3-year cycle. The potential cost savings over a 6-year cost analysis can be located in table 11. The analysis compared the cost of the 4-20-PM(10#) between 2 and 3-year life cycles. If the 4-20-PM(10#) stripes cannot last three years, calculations were performed for an increased bead and paint combination scenario of 4-23-PM(12#). The complete calculations are located in Appendix K titled "Life Cycle Cost for Centerline (Yellow) Striping on 400 AADT Roadways.

Table 11: 6-year Cost Saving Based on 2-year and 3-year Life Cycles

Life Cycle	Bead and Paint Combination	6-Year Life Cycle Cost ($)	6-Year Cost Savings ($)
2-year	4-20-PM(10#)	20,188,080	
3-year	4-20-PM(10#)	15,143,040	5,045,040
3-year	4-23-PM(12#)	17,558,640	2,629,440

The potential savings would be: 1) $2,500,000-$5,000,000 over 6-years, if the stripe can survive three years, 2) MoDOT also could save on resources if the districts would not have to check retroreflectivity on the approximately 15,000 miles of striping.

Yellow lines on Minor Roadways w/ 401-1000 AADT - Missouri has about 10,000 miles of striping in the 401-1000 AADT range. District 7 had 0% study lines below 125-mcd in Spring 2004, and had a 18% of study lines below 125-mcd in 2005, MoDOT should research increasing the bead and paint combination to possibly reduce the 18% to a even smaller number, cost saving will be achieved as re-striping amount goes down.

White Lines on Minor Roadways – As stated previously in section 3.2.3, 2nd and 4th generation resin paints study lines performed similar to each other. The bead and paint combination T-2-17-1(10#) on the test section, performed as well as the T-4-23-L(12#) combination. MoDOT should study the life of the bead and paint combination of T-2-17-1(10#). Since the majority of the MoDOT in-house striping will be located on minor roadways, a cost analysis was performed on the District 7 and 8 bead and paint combination of 4-20-L(12#) and 2-15-1(8#), respectively, and the future bead and paint combination of 4-20-PM(10#).

If T-2-17-1(10#) could provide 2-year life, a potential cost savings of $1,340,000 could be obtained. The actual calculations are located in appendix L titled “Cost for Minor Roadways with White Lines.”

The PM beads were used in the calculations so MoDOT could continue a one-bead system for the state of Missouri. Districts would have potential problems keeping type 1 and L beads separate. But, MoDOT having two different generation resin paints should not be a concern. MoDOT already has separate facility storage tanks built for white and yellow paint and the striping machines have separate storage tanks. MoDOT having a 2nd generation resin white paint and 4th generation resin yellow paint system could provide a cost savings for the state.

Conclusion and Recommendations

Re-striping and Maintenance Activity

In the effort to reduce the amount of re-striping, MoDOT districts must follow the guidelines in the “Roadway Visibility Direction”(2) and continue to study improved pavement marking products and different bead and paint combinations. The Traffic division needs to continue to provide guidance to the district traffic personnel when roadways should be re-striped due to low retroreflectivity and poor condition. At the same time, there are other measures MoDOT can take to reduce re-striping and cut the expense.

1. The investigators recommend that Central Office and District Maintenance and Traffic staff review the states best practices of reducing re-striping due to maintenance activities and develop a rehabilitation and striping plan to reduce the $720,500/year of re-striping due to unplanned maintenance work.
2. Reduce the tendency of districts to re-stripe an adequate line just because the other adequate lines are not as bright as the freshly painted line. Traffic division must stress the importance that even though a freshly re-striped line is brighter than the other adequate adjacent lines, the adjacent lines should not be re-striped. If needed, Traffic division with the support of Organizational Results could perform a customer survey on the different striping at different ages.
3. Continue to stress constant communication with stripers not to re-stripe over adequate lines by mistake.

Retroreflectivity Threshold for District Re-striping Strategy

To meet the "Percent of Stripes that meet our Customer Expectations" benchmark for minor roadways, the initial yellow stripe retroreflectivity level of 225 mcd should provide enough retroreflectivity to last 2-years on average. The white line would require a minimum of 350 mcd to last a 2nd year. Also, districts should re-stripe one-year old lines when retroreflectivity level is 200 mcd for white lines and 175 mcd for yellow lines.

MoDOT should obtain a representative history of the mcd drop on the other nine districts roadways to verify or modify the standard initial and 1st year retroreflectivity level.

Statewide Striping Strategy

MoDOT's "Roadway Visibility Direction"(2) recommends striping major roadways every year with 4th generation paint with PM beads and every other year for the minor roadways. The findings from this study is mostly consistent with this guideline, however, the study also shows there are alternatives to save MoDOT on the striping expense while maintaining the same level of performance or even improve the performance.

Yellow paint - The study found that the 4th generation resin yellow paint performed the same as the 2nd generation on the major roadways, but 4th generation resin yellow paint performed better on the minor roadways. Since the minor roadways consist of the majority of roadways being striped by MoDOT forces, the 4th generation resin yellow paint should be used on both major and minor roadways.

White paint - On the minor roadways, the 2nd generation resin white paint performed as well as the 4th generation resin white paint. MoDOT should study the 17-mils of 2nd generation resin paint with 10-lbs of type PM beads on minor roadways, this alternative has the potential to save MoDOT $1,340,000. The 2nd generation resin white paint could be implemented with 4th generation resin yellow paint since the two color paint systems are stored in separate storage tanks in the districts.

Roadways less than 1000 AADT - The yellow lines on District 7 roadways below 400 AADT were all above the retroreflectivity level of 125 mcd for two seasons, and they could last 3-years instead of 2 years. Since MoDOT has 15,000 miles of 400 AADT roadways, this could save the state between $2,500,000 and $5,000,000 over a 6-year period. Districts should build a history of roadways less than 400 AADT, so the stripers would not have to worry about 15,000 miles of roadways. The retroreflectivity levels were above 125 mcd after two years for the common surface types of chip seal, cold mix asphalt, and hot mix asphalt.

For the 10,000 miles of roadways between 401-1000 AADT, a slightly modified 4th generation resin paint and PM bead combination (thicker paint and heavier bead application) could provide a 2-year service on the yellow centerlines.

District Maintenance forces should concentrate their repair efforts to provide MoDOT's roadway surfaces a minimum 2 to 3-year life between maintenance repairs on these minor highways.

Type L vs. Type 1 Beads - The comparison between large beads and small beads to reduce accidents during wet-night traveling was not proven. The districts with the large beads were not consistently lower than small bead districts in reducing wet-night accident rates. Divisions and Districts should continue to study and improve reducing wet-night accident rates.

Implementation Plan

Traffic division should monitor the recommended 20-mils of 4th generation resin paint with 10-lbs of PM beads to verify the 2-year life of the bead and paint combination in other districts, especially the <400 ADT roadways. The information obtained should verify the recommended initial retroreflectivity readings and 1st year recommended re-striping level.

For the roadways less than 400 AADT, Organizational Results will monitor the District 7 remaining roadways to calculate the percentage of roadways less than 125 mcd. If the paint lasts 3-years, the other district's information could verify the 2 and 3-year life of the 400 AADT roadways in the future. If the paint does not last 3-years, MoDOT should initiate a study that may increase the bead and paint combination to improve the life of the line for 400 ADT roadways.

For roadways 401-1000 AADT, MoDOT should study a different bead and paint combination to possibly increase the life to 2-years, so MoDOT would not have to worry about 10,000 miles of roadways.

MoDOT should stripe test locations in every district with 17-mils of 2nd generation resin white paint with 10-lbs of PM beads to verify if this combination can survive 2-years of life.

Bibliography

1. Missouri Department of Transportation (2005). "Tracker: Measures of Departmental Performance".
2. Missouri Department of Transportation (2005). "Roadway Visibility Direction".
3. Migletz, James, Fish, Joseph K., and Graham, Jerry L., "Roadway Delineation Practices Handbook", FHWA-SA-93-001, August 1994, pg 9-11.
4. Migletz, James and Graham, Jerry, "Long-Term Pavement Marking Practices", *National Cooperative Highway Research Program Synthesis 306*, Transportation Research Board, Washington D.C., 2002, pg. 15-18.

References

1) Waterborne paint - The main materials for waterborne paint consists of a resin (harden material after curing), coalesce agent (used for the curing process), and glass beads (used to see the stripe in nighttime driving).

2) MoDOT District Bead and Paint Combinations - MoDOT's district bead and paint combinations and application rates are located in the below table.

District Bead and Paint Application Rates

District	Paint Resin	Application Rates (mils)	Glass Beads Type	Application Rate (lbs/gal)
1	2nd	14-16	Type 1	8
2	2nd	14-16	Type 1	8
3	2nd	14-16	Type 1	8
4	2nd	14-16	Type 1	8
5	2nd	14-16	Type L*	10
6	2nd	14-16	Type 1	8
7	4th	14-16	Type L	10-12
8	2nd	14-16	Type 1	8
9	2nd	14-16	Type 1	8
10	2nd	14-16	Type 1	8

*See Ref. 3.

3) Type 1 and L Beads - Type 1 beads are also called small beads, which is a general term for the industry's standard AASHTO M247 Type 1 bead. The glass bead industry produces the type L bead also called large beads, which are a larger gradation size than the type 1 gradation. The bead companies promote type L beads as providing a wet recovery benefit compared to the type 1 beads. District 5 and 7 used the type L bead from 1996-2003 and 1994-2004, respectively, for wet night retroreflectivity benefits and reducing paint track time. Track time is the time which paint requires drying sufficiently so the paint will not adhere to another surface (i.e. vehicle tire).

4) Retroreflectivity - The light that reflects back to the driver is called coefficient of retroreflected luminance, RL, or for the report the term will be called retroreflectivity. The measure of retroreflectivity is millicandela per lux per square meter (mc/lux/m²) or for the report the measure will be mcd. To obtain optimum retroreflectivity capabilities for the stripe, the beads should have 60% embedment in the paint. Thus the reason when using type L beads the paint thickness should be increased toward the 30-mil level. (3)

5) Threshold Retroreflectivity Values – MoDOT's Maintenance Division reviewed and surveyed several state DOT minimum threshold retroreflectivity values. The state DOT's values ranged from 100-150 mcd for white stripes and 80-125 mcd for yellow on dry pavement conditions. MoDOT Maintenance division decided to use the upper end values of 150-mcd for white striping and 125-mcd for yellow striping. The investigators reviewed the Minimum Retroreflectivity Guidelines for Pavement-Marking Materials Recommended by FHWA and State, County, and City Agencies.
FHWA and the other agencies recommended different levels of retroreflectivity based on different speed limits. The table below shows the recommended minimum retroreflectivity on roadways greater than 55 mph for the different governmental agencies. (4)

Agency	White (mcd)	Yellow (mcd)	Speed (mph)
FHWA	150	100	> 55
States, Counties, and Cities	100	80	> 55

Based on the FHWA and other agencies recommend minimum retroreflectivity level, MoDOT is striving for a higher level of retroreflectivity for the entire highway system.

6) First Year Preliminary Study Information - In May 2005, Maintenance division asked the investigators to provide the percentage of the first year's retroreflectivity readings that were below 125 mcd for yellow striping and below 150 mcd for white striping for roadways 3500 AADT and below. Maintenance used this information to help develop the "Roadway Visibility Direction"(2), based on the preliminary results of the project. The percentage of roadways that were below 125 and 150-mcd for the 1st year retroreflectivity information is located in the below table.

Percentage of Equal to and Less than 3500 AADT Roadways below 125 mcd for Yellow Striping and below 150 mcd for White Striping

District and Color	Generation	Percentage
7 – White	4th	23.9
8 – White	2nd	8.5
7 – Yellow	4th	1.4
8 – Yellow	2nd	18.1

MoDOT has approximately 42,000 miles of yellow stripe and 20,000 miles of white striping on minor roadways. The yellow paint with 4th generation resin had a low percentage fall below the

minimum retroreflectivity level of 125-mcd. Currently, MoDOT is stressing a one bead and paint system, thus white and yellow paint with 4th generation resin was selected for recommended use.

7) PM Beads - Since the start of the study, MoDOT, under the "Roadway Visibility Direction", has decided to use the PM beads. The PM bead gradation is between the type L and 1 bead gradations. The PM gradation does not contain the larger Type L beads and reduces the amount of the smaller type 1 gradations and fines. A full explanation of the reason for the use of the PM beads is located in MoDOT's "Roadway Visibility Direction" (2).

Appendix A: Evaluation of Waterborne Traffic Paint and Bead Combination

Date
07/18/2003

Investigation Number
PD01-021

Title
Evaluation of Waterborne Traffic Paint and Bead Combination

Research Agency
Research, Development and Technology (RDT), Maintenance Operations and Traffic Functional Units, and District 7

Principal Investigator
Daniel J Smith, Research and Development Engineer, RDT Functional Unit
Xinge Yin, Research and Development Assistant, RDT Functional Unit

Objective
Comparing combinations of 2nd generation resin paint, 4th generation resin paint, Type 1 glass and Type L glass beads to determine the most effective waterborne pavement marking combination for MoDOT.

Background and Significance of Work
The Missouri Department of Transportation is investigating new products that will provide a cost effective means to improve the durability of our highway striping paint under high volume conditions, and extensive snowplowing. This study will investigate the effectiveness of striping paint with 4th generation resin in achieving these goals, and to determine which combination of resin type, paint application thickness and bead type provides the longest effective service life.

District 7 has for several years been trying to improve the waterborne stripe being placed by District 7 stripers. The district, with the assistance of RDT, has placed a number of stripes with different types of experimental material. One of these is a waterborne stripe with the 4th generation resins (Rohm and Hass HD-21 and Dow DT400). Currently MoDOT uses 2nd generation resin in the waterborne paint. In July 1998, a test was placed using HD-21 resin on concrete pavement on new US 71. This 30-mil stripe has never been re-striped during the 3-year test. In October 2000, the testing was expanded with additional stripe being placed using HD-21 and DT400. Retroreflectivity readings were taken in November 2000 and May 2001. The performance of the 30-mil HD-21 placed in 1998 was not re-striped in the fall of 2001. Though the initial review of the performance of the HD-21 and DT400 placed in 2000 was not as good, HD-21 and DT400 had the highest retained retroreflectivity on stripe placed in 2000 on new asphalt surface compared with the existing waterborne paint and epoxy traffic marking materials. It needs to be pointed out that these 4th generation resins being tested were not strictly 4th generation resins, they were mixtures of one part of 3rd generation resins and four (4) parts of 4th generation resins, and did not meet MoDOT specifications. Even though, these results justify the intention to expand the testing of these 4th generation resins to further clarify their effectiveness. If approved, the increased striping paint durability will help MoDOT realize significant cost savings by reducing road striping frequency and the public will benefit by having highway stripes that retain their retroreflectivity through the winter.

Currently in MoDOT striping practice, Type 1 and Type L beads are used for drop-on application on traffic marking materials to provide nighttime retroreflectivity. Type L beads are larger and initially cost more than Type 1 beads. The larger beads have greater surface area than that of small beads, theoretically, not only does this allow a much greater area for bonding to the binder in which it is applied to the pavement, but also it presents a much larger reflective surface. The larger beads may also stand up above accumulated water, and improve wet night visibility. In

a correct application, the marking material needs to be of adequate thickness to embed enough of the beads to hold them. A portion of the bead is exposed. With the large beads, this portion is greater than small beads due to the size of the beads. Snowplowing will shear off both types of beads, but the larger beads may suffer more damage since more of the bead is exposed. It is a worthwhile effort to determine the cost-effectiveness of larger beads in increasing paint durability, to determine the combination of pavement marking paint and glass bead type that provides the longest effective service life. In order to do so, quantitative comparisons will be developed to determine the benefits and costs on the retroreflectivity levels and service lives among different combinations of 2nd generation resins, 4th generation resins with Type 1 and Type L beads.

Action Plan

RDT will develop the testing strategy with District 7 and the Maintenance Operations and Traffic Business Units. Contracts for paint for the 2003 striping season are in place. District 7 will be using the 4th generation paint district-wide. District 7, RDT and Maintenance Operations are paying the increased cost of the 4th generation paint over the standard MoDOT. After the work plan is finalized, the paint will be bid. The company that gets the bid will provide the required amount of 4th generation paint. District 7 will apply the paint using District 7 equipment and personnel in their routine striping operations during the striping season in 2003.

The paint will be probably installed around May 2003. Besides longitudinal striping, transverse stripes will be put down to test paint durability. After installation, BC Traffic Engineering will take the initial retroreflectivity readings using a LaserLux equipped van at the three (3) test locations. Approximately, 6-months and 12-months after installation, additional sets of readings will be taken from the same locations. The entire evaluation period will last 12 months from installation, or when average retro-reflectivity readings drop below MoDOT recommended final values of 150 mc/m^2/lux for the white paint and 100 mc/m^2/lux for the yellow paint. If the readings do not fall below the thresholds defined above at the time of 12-month after installation, further reading will be taken at 6-month intervals until the recommended minimum values are reached. BC Traffic Engineering will provide the readings to District 7 and RDT. In addition, District 7 will conduct evaluations on the transverse stripes after the installation monthly, retroreflectivity readings will be taken and a subjective durability rating will be given.

Literature Search

Determining The Longevity And Service Life Of Pavement Marking Materials, Final Report, Auburn University, Highway Research Center

Large Glass Beads Improve Wet Night Visibility, Better Roads, Vol. 58.8

Glass Bead Breakthrough Results In Improved Night Visibility, World Highways, Vol. 29.7

Method of Implementation

If research proves beneficial, RDT will submit the "Research Investigation and Implementation Form" to the Maintenance Operations and Traffic Business Units for completion, then there probably will be specifications and policy revisions.

Anticipated Benefits

Better retroreflectivity and durability through winter snowplowing are expected with the 4th generation paint application.

Research or Evaluation Period

This evaluation period will last 12 months from the test combination 4th generation resin paint installation date in 2003, or when average retro-reflectivity readings drop below 150 mc/m^2/lux for the white paint and 100 mc/m^2/lux for the yellow paint as measured with a LaserLux retroreflectometer.

Potential Funding

The company that gets the bid will provide the paint and District 7 will pay for most of the cost of paint, striping equipment and labor. RDT will fund $50,000 for the cost difference between 2nd and 4th generation resins, and the total material cost at the test locations. Maintenance Operations will also pay for part of the difference in cost

between the two resin paints. RDT will also pay the test location evaluations cost incurred with BC Traffic Engineering, and fund evaluation costs related to RDT travel expense and RDT personnel salaries.

Procedure

Tentative procedure and timeframe are as follows:

1) RDT develops work plan with District 7 and the Maintenance Operations and Traffic Business Units.

There will be three (3) test locations, featuring new asphalt pavement, old asphalt pavement and old concrete pavement separately. Waterborne paint with 2nd and 4th generation resins will be applied to new asphalt pavement, and over existing waterborne paint on old asphalt and concrete pavements. Each test location is expected to be at least 8 miles long continuously (the total length of this test will be around 24 miles), without significant difference in ADT or geometric design features along the 8-miles test segment. Snowplowing activities on each individual segment will be performed by the same maintenance crew.

Eight (8) combinations will be tried at each test location, they are 28-mils 4th generation resin with Type L beads @12 lbs./gallon, 23-mils 4th generation resin with Type L beads @12 lbs./gallon, 20-mils 2nd generation resin with Type L beads @12 lbs./gallon, 15-mils 2nd generation resin with Type L beads @10 lbs./gallon, 28-mils 4th generation resin with Type 1 beads @12 lbs./gallon, 23-mils 4th generation resin with Type 1 beads @12 lbs./gallon, 17-mils 2nd generation resin with Type 1 beads @10 lbs./gallon, and 15-mils 2nd generation resin with Type 1 beads @8 lbs./gallon. Each combination will be tried on a 1-mile long continuous segment of that test location. For each continuous 1-mile test segment, both white and yellow paint markings are required and they have the same paint thickness and beads type. See Figure 1 below for a sketch of the test set-up for a typical test location, and Table 1 shows the test scheme for all three locations.

In addition to the longitudinal centerlines and edge lines that will be striped according to the scheme described above, transverse stripes will be installed in the middle at each test location, in order to test the paint durability. For each type of paint (2nd generation and 4th generation), the same paint thickness and bead type combination will be used on the transverse stripes as on the longitudinal stripes, both white and yellow. Besides the 2nd and 4th generation paints transverse stripes, the 3rd generation paint transverse stripes will also be installed, and the same combination of paint thickness and bead type as 2nd generation paint will be used on the 3rd generation transverse stripes. Though Texas Beads are not going to be tested in longitudinal lines, this type of beads will be tried in transverse lines (It will be called Type T for simplicity in this project), with 23-mils 4th generation resin, 15-mils 3rd generation and 15-mils 2nd generation resin, while the bead application rate is the same as Type 1 bead in the same mil thickness resin. To break into details, the 15 combinations will be like this:

- 28-mils 4th generation resin with Type L beads @12 lbs./gallon, 23-mils 4th generation resin with Type L beads @12 lbs./gallon, 28-mils 4th generation resin with Type 1 beads @12 lbs./gallon, 23-mils 4th generation resin with Type 1 beads @12 lbs./gallon, 23-mils 4th generation resin with Type T beads @12 lbs./gallon,
- 20-mils 3rd generation resin with Type L beads @12 lbs./gallon, 15-mils 3rd generation resin with Type L beads @10 lbs./gallon, 17-mils 3rd generation resin with Type 1 beads @10 lbs./gallon, and 15-mils 3rd generation resin with Type 1 beads @8 lbs./gallon, 15-mils 3rd generation resin with Type T beads @8 lbs./gallon**,**
- 20-mils 2nd generation resin with Type L beads @12 lbs./gallon, 15-mils 2nd generation resin with Type L beads @10 lbs./gallon, 17-mils 2nd generation resin with Type 1 beads @10 lbs./gallon, 5-mils 2nd generation resin with Type 1 beads @8 lbs./gallon, 15-mils 2nd generation resin with Type T beads @8 lbs./gallon.

For each combination, both white and yellow paint will be put down, so there will be 24 stripes put down for durability test. These 4-inchese wide stripes will be put down at a 1-foot spacing from edge to edge, from centerline to edge line. See Figure 2 and Table 2 for a typical transverse stripes test set up plan.

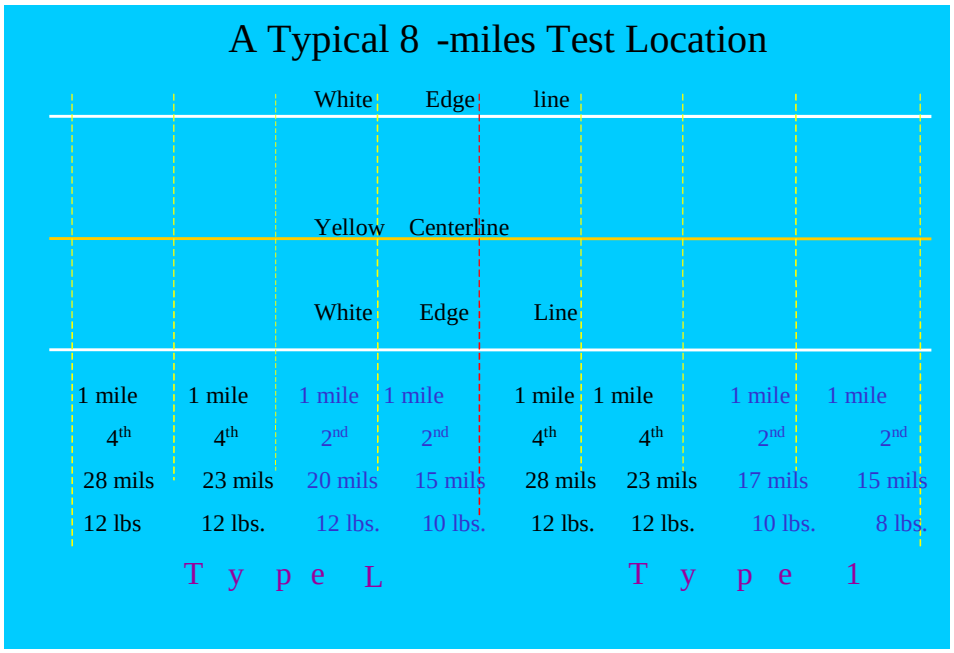


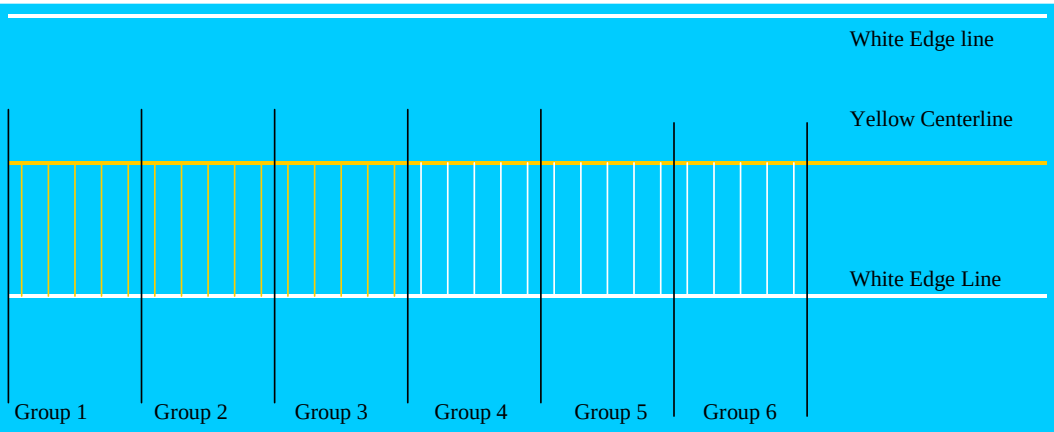
Figure 1. A Typical Test Location Set-up for Longitudinal Stripes

Table 1. Test Locations Set-up Scheme

Pavement Marking				Test Location 1	Test Location 2	Test Location 3
Resin	Bead	Thickness (Mils)	Length (Miles)	New Asphalt Pavement	Old Asphalt Pavement	Old Concrete Pavement
2nd Resin	Type L	20	1	2-20-L-NA *	2-23-L-OA	2-23-L-OC
	Type L	15	1	2-15-L-NA	2-15-L-OA	2-15-L-OC
	Type 1	17	1	2-17-1-NA	2-17-1-OA	2-17-1-OC
	Type 1	15	1	2-15-1-NA	2-15-1-OA	2-15-1-OC
4th Resin	Type L	28	1	4-28-L-NA	4-28-L-OA	4-28-L-OC
	Type L	23	1	4-23-L-NA	4-23-L-OA	4-23-L-OC
	Type 1	28	1	4-28-1-NA	4-28-1-OA	4-28-1-OC
	Type 1	23	1	4-23-1-NA	4-23-1-OA	4-23-1-OC

Note: 2-20-L-NA is a code for the test type of that location, it indicates Resin Type-Mil Thickness-Bead Type-Pavement Type, 2-20-L-NA means this test is for 2nd generation resin-20 mils-Bead L-New Asphalt Pavement.

Figure 2. Transverse Stripes Set-Up



Group 1 Yellow 4th generation: 28-mils Type L beads @12 lbs./gallon, 23-mils Type L beads @12 lbs./gallon, 28-mils Type 1 beads @12 lbs./gallon, 23-mils Type 1 beads @12 lbs./gallon, 23-mils Type T beads @12 lbs./gallon

Group 2 Yellow 3rd generation: 20-mils Type L beads @12 lbs./gallon, 16-mils Type L beads @10 lbs./gallon, 17-mils Type 1 beads @10 lbs./gallon, 15-mils Type 1 beads @8 lbs./gallon, 15-mils Type T beads @8 lbs./gallon

Group 3 Yellow 2nd generation: 20-mils Type L beads @12 lbs./gallon, 16-mils Type L beads @10 lbs./gallon, 17-mils Type 1 beads @10 lbs./gallon, 15-mils Type 1 beads @8 lbs./gallon, 15-mils Type T beads @8 lbs./gallon

Group 4 White 4th generation: 28-mils Type L beads @12 lbs./gallon, 23-mils Type L beads @12 lbs./gallon, 28-mils Type 1 beads @12 lbs./gallon, 23-mils Type 1 beads @12 lbs./gallon, 23-mils Type T beads @12 lbs./gallon

Group5 White 3rd generation: 20-mils Type L beads @12 lbs./gallon, 16-mils Type L beads @10 lbs./gallon, 17-mils Type 1 beads @10 lbs./gallon, 15-mils Type 1 beads @8 lbs./gallon, 15-mils Type T beads @8 lbs./gallon

Group 6 White 2nd generation: 20-mils Type L beads @12 lbs./gallon, 16-mils Type L beads @10 lbs./gallon, 17-mils Type 1 beads @10 lbs./gallon, 15-mils Type 1 beads @8 lbs./gallon, 15-mils Type T beads @8 lbs./gallon

Table 2. Test Locations Set-up Scheme

Pavement Marking				Test Location 1	Test Location 2	Test Location 3
Resin	Bead	Thickness (Mils)	Bead Rate (lbs./Gallon Paint)	New Asphalt Pavement	Old Asphalt Pavement	Old Concrete Pavement
4th Resin	Type L	28	12	T-4-28-L-NA	T-4-28-L-OA	T-4-28-L-OC
	Type L	23	12	T-4-23-L-NA	T-4-23-L-OA	T-4-23-L-OC
	Type 1	28	12	T-4-28-1-NA	T-4-28-1-OA	T-4-28-1-OC
	Type 1	23	12	T-4-23-1-NA	T-4-23-1-OA	T-4-23-1-OC
	Type T	15	8	T-4-15-T-NA	T-2-15-T-OA	T-2-15-T-OC
3rd Resin	Type L	20	12	T-3-20-L-NA	T-3-20-L-OA	T-3-20-L-OC
	Type L	15	10	T-3-15-L-NA	T-3-15-L-OA	T-3-15-L-OC
	Type 1	17	10	T-3-17-1-NA	T-3-17-1-OA	T-3-17-1-OC
	Type 1	15	8	T-3-15-1-NA	T-3-15-1-OA	T-3-15-1-OC
	Type T	15	8	T-3-15-T-NA	T-3-15-T-OA	T-3-15-T-OC
2nd Resin	Type L	20	12	T-2-20-L-NA *	T-2-23-L-OA	T-2-23-L-OC
	Type L	15	10	T-2-15-L-NA	T-2-15-L-OA	T-2-15-L-OC
	Type 1	17	10	T-2-17-1-NA	T-2-17-1-OA	T-2-17-1-OC
	Type 1	15	8	T-2-15-1-NA	T-2-15-1-OA	T-2-15-1-OC
	Type T	15	8	T-2-15-T-NA	T-2-15-T-OA	T-2-15-T-OC

Note: T-2-20-L-NA is a code for the test type of that location, it indicates Transverse stripe - Resin Type-Mil Thickness-Bead Type-Pavement Type, 2-20-L-NA means this test is for 2nd generation resin-20 mils-Bead L-New Asphalt Pavement.

2) Paint contract approved –February 2003
3) Install paint with 2nd generation resin and 4th generation resin at selected test locations in District 7, keeping striping report for these test locations – May ~ June 2003
4) During the installation, special attention will be paid to see if there is cracking on 23-mil 2nd generation paint – May ~ June 2003
5) BC Traffic Engineering takes initial retroreflectivity readings with LaserLux from all of the locations, and provide the measurements to RDT – May ~ June 2003
6) BC Traffic Engineering takes retroreflectivity readings with LaserLux from all of the 12 test locations, and provide the measurements to RDT – October 2003 and June 2003
7) District 7 will conduct evaluations on the transverse stripes after the installation monthly, retroreflectivity readings will be taken with LTL 2000 and a subjective durability rating will be given.
8) If retroreflectivity readings from June 2003 are still above MoDOT recommended minimum values, at these locations, continuing evaluation will be conducted at 6-month intervals from that time. Results should be furnished to RDT – after June 2003
9) District 7 is responsible to keep the test locations all through the evaluation period.
10) RDT will review the evaluation with Maintenance Operations and Traffic Business Units and District 7. For this evaluation, RDT is proposing to do a cost effectiveness analysis. The approach taken was to combine cost, effectiveness, and service life to measure cost-effectiveness. Retroreflectivity for pavement marking is measured as mc/m^2/lux (millicandela per square meter per lux). The measure of cost-effectiveness used for this study will be that cost-effectiveness equals the total installed cost per mile divided by the actual service life in years divided by the average retroreflectivity for its actual service life. As stated above, retroreflectivity readings will be taken at a 6-months interval until falling below 150 mc/m^2/lux for the white paint and 100 mc/m^2/lux for the yellow paint, the average retroreflectivity is averaged based on these readings. The resulting measure is cost per mile per mc/m^2/lux per year.
11) MoDOT RDT staff will prepare final report, conclusions, recommendations
12) Revise specifications if the evaluation is successfully completed

RDT Staffing

1- RDT Engineer
1-RDT Assistant

Equipment

State Car

Budget

- **RDT Expense**
  - BC Traffic Engineering Evaluation Cost
    3 (test locations) x (20 miles) (length of each test location) x $22.95/driven mile x 3 (lines, 2 edge lines + one center line) x 4 (evaluations) = $16,524

  - Material Cost $50,000 + 7 cents/foot x 5280 x 8 miles x 3 x 3 = $76,611

  - Work plan composing
    Personnel Salaries:
    1- RDT Engineer (5 days)
    (1 @ $1367 x 1.693) = $2314
    1- RDT Assistant (10 days)
    (1 @ $1778 x 1.693) = $3010

- 3-weeks report composing
  1 – RDT Engineer
  (1 @ $3417 x 1.693) = $5785

- 4-weeks change specification
  1 – RDT Engineer
  (1 @ $4556 x 1.693) = $7713

Total RDT Expense = $111, 155

Appendix B: The 2nd and 4th Generation Paint Snowplowing Damage Issue

02-02-2004

In the effort of comparing 2nd and 4th generation paints, durability is essential to the evaluation. Normal traffic and snowplowing are the two main forces that remove the paint and beads away from the roadway. Between the two, snowplowing is more elusive to capture, simply because there are so many variables associated with snowplowing. The type of the snowplow blade, the pavement quality, the operator, the geometric features of the road, etc., it is impossible to set a control. At the same time, snowplowing is a key factor to the evaluation.

RDT, Maintenance and District 7 investigators gathered and brainstormed how to capture the different variables associated with snowplowing. The proposed plan is as follows.

District 7 is striping all their roadways with 4th generation paint and Type L beads, while the neighboring District 8 is striping their roadways with 2nd generation paint and Type l beads. These two districts have similar climate. Roadways that meet certain criteria will be selected, after that retroreflectivity readings will be taken with LaserLux van, most likely, by BC Engineering.

Roadways from both districts have to the meet the same criteria. AADT classification, roadway surface type and pavement condition. A matrix is designed for this purpose. TMS will provide information to identify these roadways. The proposal will scatter the roadways around the districts; the variables associated with snowplowing should be countered. After that, District personnel will perform field observations on these roadways for potential candidates. After these candidate routes are selected, a list will be sent to BC Engineering for them to take retroreflectivity readings.

During this process, an important question is how to sample these routes. For the roadways that have the same AADT range and surface condition, LaserLux will need to take at least 720 readings to maintain a 95% confidence level. If the 720 or more readings are taken at 10 feet intervals, a segment of at least 7,200 feet long will be needed on each candidate roadway to run the LaserLux van.

Based on the reasoning above, RDT proposes that the readings should be taken from 1.5 miles segment of each route being selected. This will give us about 790 random readings (taken at 10 feet intervals) to maintain a 95% above confidence level, which is sufficient for this evaluation. But the readings do not have to be taken at 10 feet intervals. If a different interval is needed, the roadway segment length will change accordingly.

At the same time, District personnel much stress the following issues:

1. Do not select routes that will have maintenance activities on them during the evaluation period.
2. Do not re-stripe the routes being selected.

Appendix C: MoDOT Test Sections

The three test locations were located on Rt. 37, Newton County on new asphalt, Rt. 37, Jasper County on old asphalt, and Rt. 171, Jasper county on old concrete.

The test locations were located in three different areas. The test sections were subjected to different snowplowing, weather conditions, and traffic volume, but the eight individual test combinations were treated by same snowplowing, weather, and traffic volume.

For simplicity, the three test sections were totaled and averaged over the seasons as located below titled “MoDOT Test Section Averaged”.

MoDOT Test Sections

MODOT County	MODOT ROUTE	Line Type	Test Code	Fall 2003 AVG MCD	Spring 2004 AVG MCD	Fall 2004 AVG MCD	Spring 2005 AVG MCD
				Fall03	Spring04	Fall04	Spring05
Jasper	MO 37	CL	T-4-28-L-OA	235	156	151	139
Jasper	MO 37	CL	T-4-23-L-OA	281	161	189	147
Jasper	MO 37	CL	T-2-20-L-OA	238	129	101	101
Jasper	MO 37	CL	T-2-15-L-OA	203	129	134	117
Jasper	MO 37	CL	T-4-28-1-OA	184	122	120	96
Jasper	MO 37	CL	T-4-23-1-OA	144	146	140	95
Jasper	MO 37	CL	T-2-17-1-OA	158	125	136	104
Jasper	MO 37	CL	T-2-15-1-OA	150	110	133	101

MODOT County	MODOT ROUTE	Line Type	Test Code	Fall 2003 AVG MCD	Spring 2004 AVG MCD	Fall 2004 AVG MCD	Spring 2005 AVG MCD
				Fall03	Spring04	Fall04	Spring05
Newton	MO 37	CL	T-4-28-L-NA	271	264	264	180
Newton	MO 37	CL	T-4-23-L-NA	273	168	173	152
Newton	MO 37	CL	T-2-20-L-NA	235	213	198	147
Newton	MO 37	CL	T-2-15-L-NA	176	156	145	129
Newton	MO 37	CL	T-4-28-1-NA	153	153	159	114
Newton	MO 37	CL	T-4-23-1-NA	159	149	150	102
Newton	MO 37	CL	T-2-17-1-NA	166	168	169	108
Newton	MO 37	CL	T-2-15-1-NA	156	110	141	105

MODOT County	MODOT ROUTE	Line Type	Test Code	Fall 2003 AVG MCD	Spring 2004 AVG MCD	Fall 2004 AVG MCD	Spring 2005 AVG MCD
				Fall03	Spring04	Fall04	Spring05
Jasper	171	LEL	T-4-28-L-OC	307	225	209	187
Jasper	171	LEL	T-4-23-L-OC	273	247	230	191
Jasper	171	LEL	T-2-20-L-OC	216	170	122	141
Jasper	171	LEL	T-2-15-L-OC	178	164	142	124
Jasper	171	LEL	T-4-28-1-OC	192	161	160	122
Jasper	171	LEL	T-4-23-1-OC	187	158	142	122
Jasper	171	LEL	T-2-17-1-OC	217	188	172	136
Jasper	171	LEL	T-2-15-1-OC	201	167	165	120

MoDOT Test Sections Averaged (Yellow Paint)

Test Code	Fall 2003 AVG MCD	Spring 2004 AVG MCD	Fall 2004 AVG MCD	Spring 2005 AVG MCD
	Fall03	Spring04	Fall04	Spring05
T-4-28-L(12#)	271	215	208	169
T-4-23-L(12#)	276	192	197	163
T-2-20-L(12#)	230	171	140	130
T-2-15-L(10#)	186	150	140	123
T-4-28-1(12#)	176	145	146	111
T-4-23-1(12#)	163	151	144	106
T-2-17-1(10#)	180	160	159	116
T-2-15-1(8#)	169	129	146	109

MODOT County	MODOT ROUTE	Line Type	Test Code	Fall 2003 AVG MCD	Spring 2004 AVG MCD	Fall 2004 AVG MCD	Spring 2005 AVG MCD
				Fall03	Spring04	Fall04	Spring05
Newton	MO 37	N EL	T-4-28-L-NA	317	207	210	170
Newton	MO 37	N EL	T-4-23-L-NA	293	229	213	172
Newton	MO 37	N EL	T-2-20-L-NA	286	181	174	144
Newton	MO 37	N EL	T-2-15-L-NA	285	191	183	133
Newton	MO 37	N EL	T-4-28-1-NA	291	190	171	130
Newton	MO 37	N EL	T-4-23-1-NA	300	191	170	138
Newton	MO 37	N EL	T-2-17-1-NA	331	225	225	174
Newton	MO 37	N EL	T-2-15-1-NA	324	212	171	160

MODOT County	MODOT ROUTE	Line Type	Test Code	Fall 2003 AVG MCD	Spring 2004 AVG MCD	Fall 2004 AVG MCD	Spring 2005 AVG MCD
				Fall03	Spring04	Fall04	Spring05
Newton	MO 37	S EL	T-4-28-L-NA	301	220	242	213
Newton	MO 37	S EL	T-4-23-L-NA	255	192	194	176
Newton	MO 37	S EL	T-2-20-L-NA	336	204	218	183
Newton	MO 37	S EL	T-2-15-L-NA	284	187	192	159
Newton	MO 37	S EL	T-4-28-1-NA	304	181	195	149
Newton	MO 37	S EL	T-4-23-1-NA	297	167	172	131
Newton	MO 37	S EL	T-2-17-1-NA	328	207	207	187
Newton	MO 37	S EL	T-2-15-1-NA	314	200	185	153

MODOT County	MODOT ROUTE	Line Type	Test Code	Fall 2003 AVG MCD	Spring 2004 AVG MCD	Fall 2004 AVG MCD	Spring 2005 AVG MCD
				Fall03	Spring04	Fall04	Spring05
Jasper	MO 37	SB EL	T-4-28-L-OA	338	205	175	219
Jasper	MO 37	SB EL	T-4-23-L-OA	313	205	135	204
Jasper	MO 37	SB EL	T-2-20-L-OA	301	167	112	162
Jasper	MO 37	SB EL	T-2-15-L-OA	277	137	109	144
Jasper	MO 37	SB EL	T-4-28-1-OA	331	159	150	161
Jasper	MO 37	SB EL	T-4-23-1-OA	313	160	155	167
Jasper	MO 37	SB EL	T-2-17-1-OA	313	167	201	164
Jasper	MO 37	SB EL	T-2-15-1-OA	309	155	182	141

MODOT County	MODOT ROUTE	Line Type	Test Code	Fall 2003 AVG MCD	Spring 2004 AVG MCD	Fall 2004 AVG MCD	Spring 2005 AVG MCD
				Fall03	Spring04	Fall04	Spring05
Jasper	MO 37	NB EL	T-4-28-L-OA	357	213	165	185
Jasper	MO 37	NB EL	T-4-23-L-OA	354	191	149	136
Jasper	MO 37	NB EL	T-2-20-L-OA	316	183	165	113
Jasper	MO 37	NB EL	T-2-15-L-OA	323	185	170	119
Jasper	MO 37	NB EL	T-4-28-1-OA	408	205	223	121
Jasper	MO 37	NB EL	T-4-23-1-OA	394	199	183	122
Jasper	MO 37	NB EL	T-2-17-1-OA	333	186	207	109
Jasper	MO 37	NB EL	T-2-15-1-OA	336	179	166	109

MODOT County	MODOT ROUTE	Line Type	Test Code	Fall 2003 AVG MCD	Spring 2004 AVG MCD	Fall 2004 AVG MCD	Spring 2005 AVG MCD
				Fall03	Spring04	Fall04	Spring05
Jasper	171	LL	T-4-28-L-OC	411	223	212	170
Jasper	171	LL	T-4-23-L-OC	359	212	189	184
Jasper	171	LL	T-2-20-L-OC	282	204	165	145
Jasper	171	LL	T-2-15-L-OC	253	166	155	128
Jasper	171	LL	T-4-28-1-OC	342	160	168	131
Jasper	171	LL	T-4-23-1-OC	352	168	161	130
Jasper	171	LL	T-2-17-1-OC	374	174	198	159
Jasper	171	LL	T-2-15-1-OC	366	185	184	140

MODOT County	MODOT ROUTE	Line Type	Test Code	Fall 2003 AVG MCD	Spring 2004 AVG MCD	Fall 2004 AVG MCD	Spring 2005 AVG MCD
				Fall03	Spring04	Fall04	Spring05
Jasper	171	REL	T-4-28-L-OC	442	192	206	178
Jasper	171	REL	T-4-23-L-OC	401	204	188	123
Jasper	171	REL	T-2-20-L-OC	307	170	157	147
Jasper	171	REL	T-2-15-L-OC	300	152	147	117
Jasper	171	REL	T-4-28-1-OC	351	173	186	165
Jasper	171	REL	T-4-23-1-OC	355	181	180	118
Jasper	171	REL	T-2-17-1-OC	386	187	214	197
Jasper	171	REL	T-2-15-1-OC	368	200	208	172

MoDOT Test Sections Averaged (White Paint)

Test Code	Fall 2003 AVG MCD	Spring 2004 AVG MCD	Fall 2004 AVG MCD	Spring 2005 AVG MCD
	Fall03	Spring04	Fall04	Spring05
T-4-28-L(12#)	361	210	202	189
T-4-23-L(12#)	329	206	178	166
T-2-20-L(12#)	305	185	165	149
T-2-15-L(10#)	287	170	159	133
T-4-28-1(12#)	338	178	182	143
T-4-23-1(12#)	335	178	170	134
T-2-17-1(10#)	344	191	209	165
T-2-15-1(8#)	336	189	183	146

Appendix D: Wet-Night Accident Information

Different Wet-Night Accident Rates:

Wet-Night Total Accident Rate
Wet-Night Head On Acc Rate
Wet-Night Sideswipe Acc Rate
Wet-Night Fixed Object Acc Rate
Wet-Night Out of Control Acc Rate

The accident rates were obtained from the following criteria:

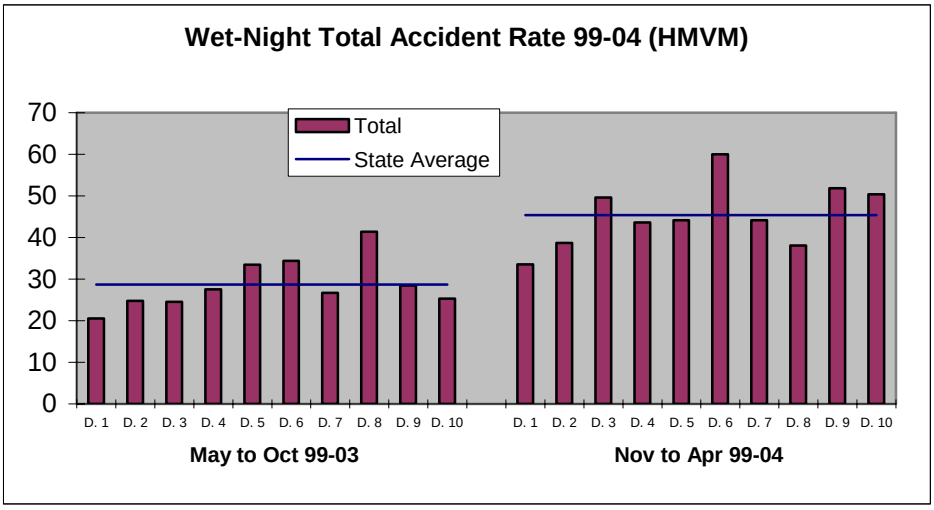
Two Lane & Super 2-Lane Routes
Rural area designation
Speed Limit >= 55 MPH
By District

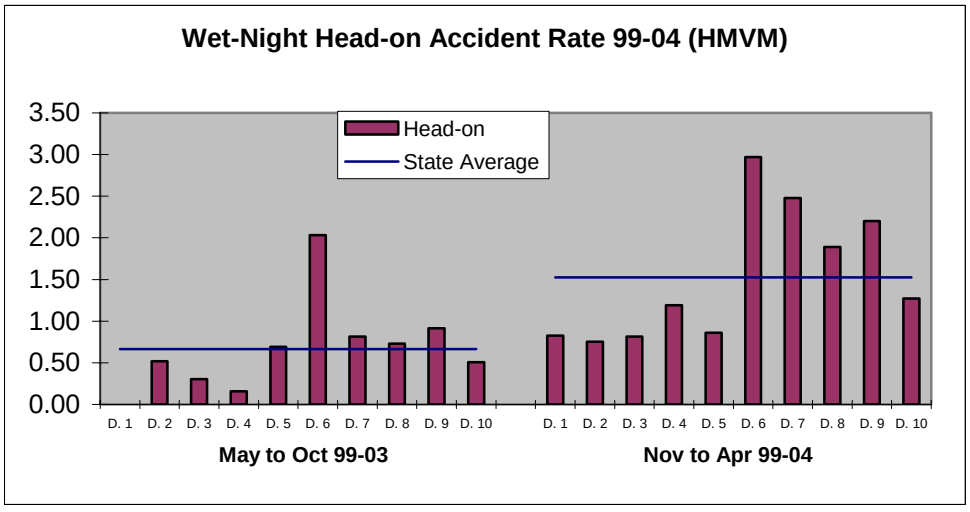
This information was split for time periods of:

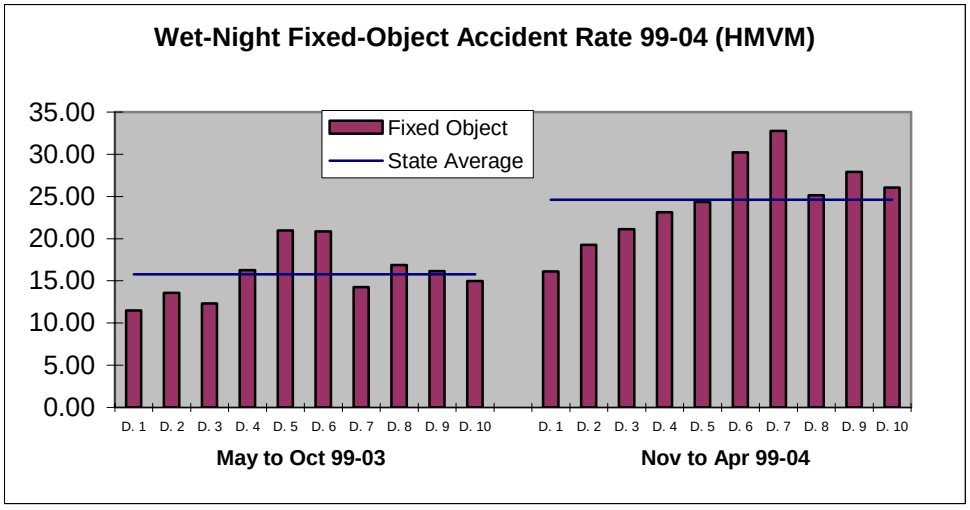
May to October (summer)
November to April (winter)

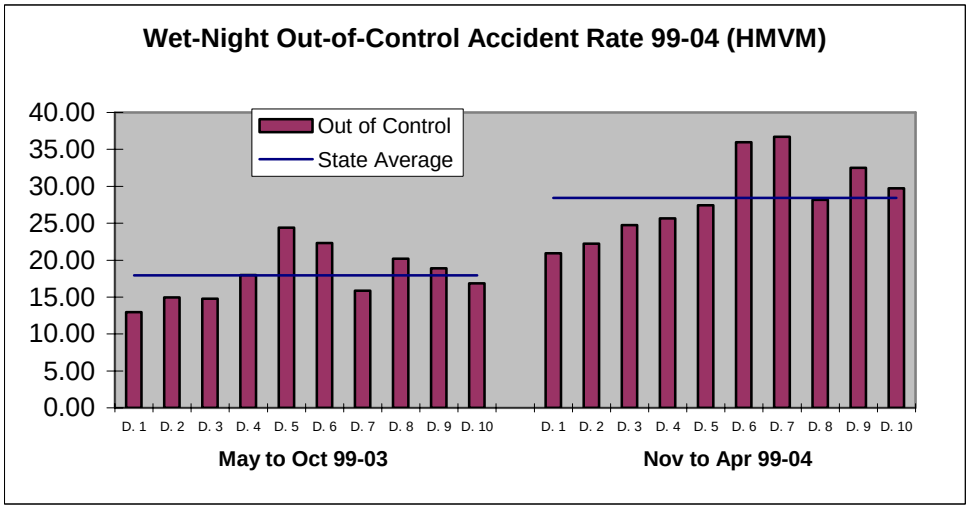
For the AADT/VMT information, a rural 2-lane Principal Arterial was used to determine that 25% of the AADT/VMT is accounted for during the period of 7PM to 7AM (assumed general nighttime period for the year). Also, it was estimated from an ATR site that 52% of the traffic occurred during the summer and that 48% of the traffic occurred during the winter.

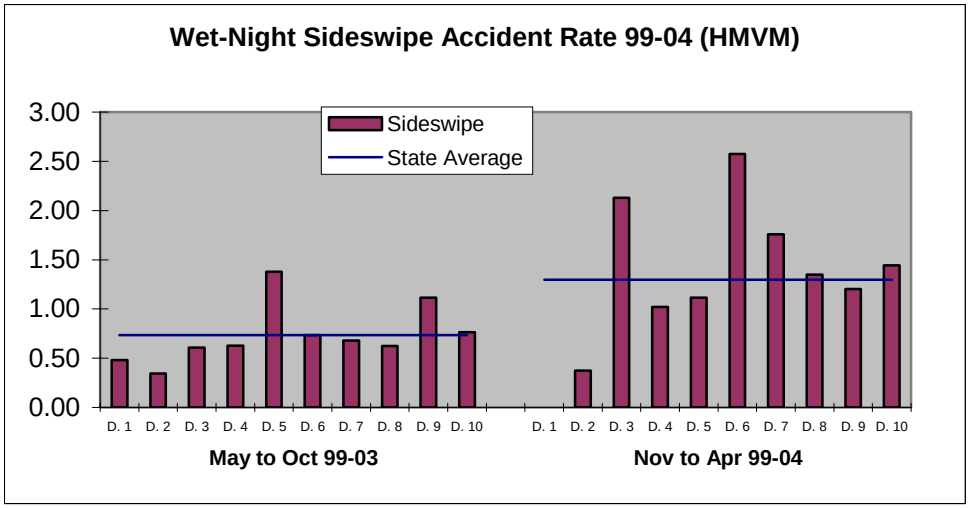
Appendix E: Statewide Performance of Type 1 and L Beads






Wet-Night Fixed-Object Accident Rate 99-04 (HMVM)
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Fixed Object
State Average
D. 1 D. 2 D. 3 D. 4 D. 5 D. 6 D. 7 D. 8 D. 9 D. 10
D. 1 D. 2 D. 3 D. 4 D. 5 D. 6 D. 7 D. 8 D. 9 D. 10
May to Oct 99-03
Nov to Apr 99-04


Wet-Night Out-of-Control Accident Rate 99-04 (HMVM)
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Out of Control
State Average
D. 1 D. 2 D. 3 D. 4 D. 5 D. 6 D. 7 D. 8 D. 9 D. 10
D. 1 D. 2 D. 3 D. 4 D. 5 D. 6 D. 7 D. 8 D. 9 D. 10
May to Oct 99-03
Nov to Apr 99-04


Wet-Night Sideswipe Accident Rate 99-04 (HMVM)
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Sideswipe
State Average
D. 1 D. 2 D. 3 D. 4 D. 5 D. 6 D. 7 D. 8 D. 9 D. 10
May to Oct 99-03
D. 1 D. 2 D. 3 D. 4 D. 5 D. 6 D. 7 D. 8 D. 9 D. 10
Nov to Apr 99-04

Appendix F: Evaluation of Laserlux Readings

Laserlux readings can be a very helpful tool to determine if a pavement marking needs to be re-striped or can provide good guidance for another season. The data from the contractor contains two valuable pieces of information that can be used to make this determination.

The primary data is the retroreflectivity reading. The following are the minimum numbers that should be used to determine if a stripe could be skipped being re-striped before the end of the season.

Color	R_L mcd/m^2/lux
White	150
Yellow	100

Lines with readings below these numbers shall be re-striped this season.

Another component of determining the quality of a line is the subjectivity rating. This rating, which is done as the laserlux readings are being taken, is a determination of the "look" of the line. A subjectivity rating of 5 is given to a brand new line and a rating of 1 indicates a line with very little material remaining.

Since it is possible to have high retro numbers but a low subjectivity rating, the following matrices were developed as part of the PMMS effort, to combine these two effects to determine the quality of a line. These matrices are still under review but can be used to help with the decision to re-stripe or not.

Condition Matrix

Yellow Markings

		R_L mcd/m^2/lux				
		<100	**100-125**	**125-150**	**150-175**	**>175**
Sub Rate	**5**	C	C	B	A	A
	4	C	C	B	A	A
	3	D	D	C	B	B
	2	F	D	C	C	C
	1	F	F	D	D	D

Condition Matrix

White Markings

		R_L mcd/m^2/lux				
		<100	**100-150**	**150-200**	**200-250**	**>250**
Sub Rate	**5**	C	C	B	A	A
	4	C	C	B	A	A
	3	D	D	C	B	B
	2	F	D	C	C	C
	1	F	F	D	D	D

A = Do Not Re-stripe
B = Field Check to Evaluate Line
C, D & F = Re-stripe

Appendix G: Subjective Rating for Stripe

(Draft 11/17/04)

BC proposed to use a 1-5 subjective rating for striping. (1 line is gone; 5 is new condition.)

District 7 has tried to develop a better explanation of the rating scale. There are actually 3 components in a rating scale. Retroreflectivity reading, daytime visual, and nighttime visual.

Daytime Observation

1 Mostly gone
2 Very spotty with patchy areas, 30 to 60% of paint and beads in place
3 Small areas of bead loss, but line still consistent, 60 to 70% of paint and beads in place
4 Very little damage with good bead coverage
5 Excellent condition as if installed within the season

Nighttime Observation

1 Minimal amount of line is visible. Delineation is not provided.
2 60 to 70% of line is dark. Some sections have less than adequate delineation. Less than 5 skips are visible.
3 30 to 40% of line is dark. No section has less than adequate delineation. At least 6 skips are visible.
4 Less than 5% of line is dark. Line is bright. At least 10 skips are visible.
5 Line in new condition with no dark areas. More than 12 skips are visible. Line is not only bright but "glows". Delineation is distinguishable beyond the lit area of the headlights.

We have not reconciled the rating between daytime, nighttime and retroreflectivity readings.

Appendix H

2004 MoDOT Re-striping Pavement Marking Lines Due to Maintenance Activities

Re-striping Reason	Cost of Paint ($/mile)	Labor & Equipment Cost ($/mile)	MoDOT Striping Program	Re-striping Cost of Material	Re-striping Cost of Labor	Total Re-striping Cost
Maintenance						
4Y-20-PM(10#)	233.26	71.28	2366	551,893	168,648	720,542

Striping Cost - New Proposal-White (4W-20-PM(10#)) = $225.55/mile, Yellow (4Y-20-PM(10#)) = $240.96/mile; Average Cost = $233.26/mile
Labor Cost consist of Labor @ $0.0088/ft, Cash@$0.0006/ft, Equipment@ $0.0041 for a Total Cost of $0.0135/ft. or $71.28/mile.
The calculated re-striping mileage of MoDOT roadways due to maintenance activities is 2,366 miles.

Appendix I: Test Section MCD Drop

The average 4th generation resin paint retroreflectivity readings were subtracted between Fall 2003 and Spring 2004 and Spring 2004 and Spring 2005. The MCD drop between seasons is located under the title "Average MCD Drop on Controlled Test Lines".

Yellow	Fall 2003	Spring 2004	Spring 2005	Fall 03 Spring 04	Spring 04 Spring 05
Test Code	AVG MCD	AVG MCD	AVG MCD	Drop	Drop
	Fall03	Spring04	Spring05		
T-4-28-L(12#)	271	215	169	56	46
T-4-23-L(12#)	276	192	163	84	29
T-4-28-1(12#)	176	145	111	31	34
T-4-23-1(12#)	163	151	106	12	45
Average				46	38

White	Fall 2003	Spring 2004	Spring 2005	Fall 03 Spring 04	Spring 04 Spring 05
Test Code	AVG MCD	AVG MCD	AVG MCD	Drop	Drop
	Fall03	Spring04	Spring05		
T-4-28-L(12#)	361	210	189	151	21
T-4-23-L(12#)	329	206	166	123	40
T-4-28-1(12#)	338	178	143	160	35
T-4-23-1(12#)	335	178	134	157	44
Average				148	35

Average MCD Drop on Controlled Test Lines

	Fall 03 Spring 04 Drop	Spring 04 Spring 05 Drop
Yellow	46	38
White	148	35

Appendix J: Recommended Threshold Retroreflectivity Numbers

Yellow Striping:
Reviewing the yellow study lines, method 3 showed that the lowest mcd is 143, which is 18-mcd higher than 125-mcd. Method 3's average of 177-mcd would be on the upper end of Method 1 range of 139-183 mcd. The yellow controlled test section drop of 38-mcd added to the minimum retroreflectivity level of 125 mcd would produce a 163-mcd level. The investigators decided a 1st year level of 175 mcd for yellow line should provide a 125-mcd yellow line into the 2nd year, as shown in table 9.

The investigators tried to provide a possible initial application retroreflectivity reading that would provide a 2-year level of service for the 4th generation resin paint and PM beads. The Missouri Standard Specifications for Highway Construction require the paint lines to have a minimum initial reading of 225 mcd for yellow lines. Using the first year mcd drop of the controlled test sections of 46 mcd and added to the 175 mcd first year standard, the initial reading would be 221. The 225 mcd standard would provide enough retroreflectivity to survive two-years, as shown in table 9.

White Striping:
The white study lines of all three methods had average retroreflectivity levels between 181-186 mcd for the 1st year reading. The controlled test sections had an average drop of 35-mcd. Adding 35-mcd to the minimum white retroreflectivity level of 150 mcd produced a 1st year retroreflectivity level of 185-mcd for white lines. Since method 1 average was within the other readings, 1st year level of 185 mcd did not appear to be conservative. The investigators decided to use MoDOT's current retroreflectivity re-stripe level of 200-mcd for 1st year re-stripe retroreflectivity level as shown in table 9. The MoDOT standard specifications have a minimum initial retroreflectivity level of 300 mcd. The controlled test section retroreflectivity reading drop from initial to 1st year retroreflectivity reading was calculated to be 148 mcd. With the 1st year retroreflectivity drop of 148 mcd added to the 1st year re-striping level of 200 mcd, the initial retroreflectivity would be 350 as shown in table 9.

Appendix K: Life Cycle Cost for Centerline* (Yellow) Striping on 400 AADT Roadways

	4-20-PM(10)**		4-20-PM(10)		4-23-PM(12)	
	2-year	Cycle	3-year	Cycle	3-year	Cycle
Year	$/ft.***	Cost/year	$/ft.	Cost/year	$/ft.	Cost/year
Initial	$0.0591	4,680,720	$0.0591	4,680,720	$0.0685	5,425,200
1						
2	0.0621	4,918,320				
3			0.0636	5,037,120	0.0738	5,844,960
4	0.0652	5,163,840				
5						
6	0.0685	5,425,200	0.0685	5,425,200	0.0794	6,288,480
Total Cost	$0.2549	20,188,080	$0.1912	15,143,040	$0.2217	17,558,640

	20,188,080	20,188,080
	15,143,040	17,558,640
6-year Savings	5,045,040	2,629,440

* The centerline mileage for less than 400 ADT is 10,822 miles.
For calculations, the centerline miles was multiplied between 1.25 - 1.50 to calculate in the different striping scenarios.
The amount of striping miles used for the calculations is 15,000 miles.
** 4-20-PM(10) = 4-4th generation paint, 20-20 mil thickness, PM-bead type, 10-10 lbs. of beads per ft.
*** 4th generation paint @ $8.282/gal., Type PM beads @ $0.27/lb, Labor @$0.0088/ft., Cash @ $0.0006/ft.
Equipment @ $0.0041/ft., inflation rate = 2.5%

Appendix L: Life Cycle Cost for Minor* White Striping Roadways

	4-20-PM(10)**	
Year	$/ft.***	Cost/year
Initial	$0.0562	5,934,720

2-17-PM(10)	
$/ft.	Cost/year
$0.0435	4,593,600

	5,934,720
	4,593,600
Total Savings	1,341,120

* The mileage for minor white striping roadways was calculated to be 20,000 miles by Maintenance.
** 4-20-PM(10) = 4-4th generation paint, 20-20 mil thickness, PM-bead type, 10-10 lbs. of beads per ft.
*** 4th generation paint @ $7.580/gal., 2nd generation paint @ $5.806/gal., Type PM beads @ $0.27/lb, Labor @$0.0088/ft., Cash @ $0.0006/ft., Equipment @ $0.0041/ft.